REPORT MDC E0448

SIMULATIONS TO SUPPORT SYSTEMS ENGINEERING/INTEGRATION

FINAL REPORT

CR-120094

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY • EAST

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FINAL REPORT

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1.0 SUMMARY

This study was conducted to define simulations required to support systems engineering and integration efforts related to the Space Shuttle development program. The study was accomplished concurrently with the McDonnell Douglas Astronautics Company Space Shuttle Phase B study activities.

The study identified 62 Booster vehicle and 69 Orbiter vehicle analyses and studies requiring support of simulation tasks. A summary list of these analyses and studies is presented in Figure 3.1.1-1.

Simulation Requirements Descriptions (SRD's) were prepared for each Booster and Orbiter simulation task. These SRD's documented in detail the following; the objective of each simulation task, the justification for using simulation techniques, the description of the simulation task, the generic facility requirements, and the schedule showing relation to program milestones.

Eleven Booster simulation facilities and sixteen Orbiter simulation facilities were identified as generic facility types required to perform the simulations listed in the study. A list summarizing facility requirements is presented in Figure 3.1.2-1.

Results of the study primarily consist of the individual Booster and Orbiter simulation tasks organized into two alternate simulation plans for each vehicle. Plan I emphasizes a high technical penetration with low program risk resulting in higher cost. Plan II represents adequate technical penetration with acceptable program risk and lower cost.

The resulting simulation plans were phased with the Booster and Orbiter Phase C/D vehicle development schedules and were identified with generic facility requirements. Figures 3.2.1-3 and 3.2.1-4 show the Booster and Orbiter facility loading for Plan I. This diagram summarizes the simulation activities for both Booster and Orbiter by showing facility requirements, number of simulation tasks scheduled in each facility and the expected utilization of each facility in terms of hours per calendar period.

2.0 INTRODUCTION

This report documents details of the Space Shuttle Simulation Planning Study conducted by the McDonnell Douglas Astronautics Company for NASA, Marshall Space Flight Center under contract NAS 8-26920.

Description of the study tasks and results are discussed in this final report.

2.1 Background

Simulation has been used successfully as a systems engineering and integration tool in development of the Saturn launch vehicle. The use of simulation in development of Gemini, Apollo, and Skylab manned spacecraft is well documented. In addition to the space program, simulation techniques are used extensively in development of military and commercial aircraft and the training of pilots.

The complex design problems inherent in dual roles of the Space Shuttle vehicle (i.e., manned spacecraft and trisonic aircraft) present many analyses and studies requiring solutions through use of simulation techniques. Experience on past programs has shown simulation to be a significant part of the overall program cost. An effective planning activity can do much to provide cost saving simulation programs for the support of Booster and Orbiter vehicle development.

2.2 Scope of Study

The scope of this study is based on the premise that one center/contractor team will be responsible for the Booster vehicle development and another center/contractor team will be responsible for the Orbiter vehicle development. Therefore; the simulation activities defined in this study are divided between Booster and Orbiter vehicle responsibilities. Some simulations are listed as Combined Booster and Orbiter simulations. These simulation types fall in two categories, vehicle integration and launch vehicle development. Since the integrator role will be assumed by the Orbiter center/contractor, simulations dealing with integration responsibilities are considered to be Orbiter simulation tasks. Simulations related to analyses and studies of the combined launch vehicle for mission phases prior to and including separation are considered to be responsibility of the Booster center/contractor. Each center/contractor team will do as much simulation work as is necessary to assure the vehicle for which they are responsible will meet specified performance goals. In this respect, the two alternate plans

for Booster and Orbiter teams were developed by this study to bracket a range of technical penetration and cost. The first plan presents a deep technical penetration evidenced by parallel simulation activities on the part of each center/contractor team. The second alternate plan calls for only essential simulations to be done resulting in less duplication of efforts, the combining of similar simulations, and the complete elimination of non-essential simulations.

3.0 APPROACH

The approach used in this study may be examined by looking in detail at the two major tasks accomplished; the definition of Space Shuttle simulation requirements, and the development of an integrated simulation plan.

3.1 Task I - Define Space Shuttle Simulation Requirements

The objective of this task was to define and document simulation requirements for support of systems engineering/integration activities with the Space Shuttle project. This task was accomplished by first identifying analyses and studies requiring simulation and then preparing Simulation Requirements Descriptions (SRD's). The individual Simulation Requirements Description documents each simulation task in sufficient detail to facilitate planning and scheduling of the total simulation program.

3.1.1 Identify Analyses and Studies Requiring Simulation - The process of identifying analyses and studies requiring simulation entailed applying each candidate simulation task to a set of criteria which was defined at the outset of the study. Considerations in selection of the final list of simulations included the following; a definition of simulation as viewed in the context of this study, the identification by interfacing area requiring simulation, the area of contractor responsibility, and the screening process itself.

Definition of Simulation - The term simulation has a multitude of connotations depending on the reader's point of view, but for purposes served by this study, simulation shall be considered in the following context. Simulation shall involve the use of computerized mathematical models of physical systems in a unique manner to solve a particular systems engineering/integration problem. The "unique manner" referred to is intended to separate simulation from the context of normal computation tasks that support engineering activities. Computer studies representing a routine computational exercise such as static structural analysis or mass properties computations are not considered to be a simulation by this definition. The "unique manner" refers to a dynamic situation, involving the solution of a problem in which certain key parameters are constantly changing. Examples of this type of solution, using math models of physical systems to solve dynamic problems, include propulsion-structural vehicle interactions (SRD 3.2.3.1), or evaluation of handling characteristics of the vehicle using man-in-the-loop simulation studies (SRD 1.1.1.1.2).

By adopting the above definition this study has gone beyond the standard man-in-the-loop context of simulation involving math models interfacing with hardware (crew station), to include all-software simulations of systems dynamics such as the investigation of propulsion-structural vehicle interactions. Two exceptions to this guideline for defining simulations are static crew station mockups (e.g., SRD's 1.1.5.1.1 and 1.1.5.1.2) and propellant handling models (SRD 5.1.1.1.5). The crew station mockups were included because of their traditional role of being related to man-in-the-loop engineering and training simulations. Propellant handling models, which involve physical simulations, are included to contrast with the computer math model simulations of this study, and to present an example of a simulation required to support systems design in which a computer math model is not feasible.

Identification by Interfacing Area - The efforts associated with systems engineering and integration involve analyzing interfaces of various subsystems and disciplines exhibiting complex systems interactions. These interactions may be analyzed and evaluated by use of simulation techniques. The method of arriving at a list of candidate simulation tasks involved contemplating a given interfacing area (e.g., man-machine) and identifying all possible simulations that fall within that area. This exercise was not intended as a convenient labeling process for a quantity of simulation tasks, but as a technique for systematically finding and identifying all candidate simulation tasks. The following interfacing areas were used as criteria for identifying simulations.

Man/machine: Includes simulations that use man-in-the-loop, combined with actual or simulated hardware, and computer mechanizations of mathematical models of vehicle subsystems, vehicle performance, and external environment.

Man/dynamics: Includes simulation techniques that enable study of actual dynamic and physical environment effects on human performance.

Machine/dynamics: Includes simulations that involve varied combinations of mathematical models and actual hardware to study effects of dynamic external environment on the vehicle as a system.

Dynamic/subsystem: Includes simulations that involve varied combinations of mathematical models and actual hardware to study effects of external dynamic environment on vehicle subsystems.

Subsystem/subsystem: Includes simulations that involve varied combinations of mathematical models and actual hardware to study interaction of vehicle subsystems.

Hardware/software: Includes software/hardware interface verification and use of simulation techniques in actual flight software development for onboard computers.

Vehicle/operations: Includes use of simulation techniques in solving problems related to logistics and operations aspects of the Space Shuttle program.

Software/software: Includes software simulations of hardware devices and systems to develop and verify onboard software design and integration.

Vehicle/subsystem: Includes simulations that involve subsystem mathematical models and their interrelation with total vehicle operation.

Two additions and one deletion were made to the original list of interfacing areas outlined in the Statement Of Work. The additions, software/software and vehicle/subsystem were included to improve the definition of interfacing areas. The area of dynamic/subsystem was deleted because it connotes interaction of a subsystem with a dynamic environment. This type activity characteristically entails qualification or development testing to determine ability of a system to meet specification (e.g., temperature/vibration tests of selected portions of an avionics subsystem). Although the test might be considered a simulation of environmental effects on a system, the activity does not meet the previously stated definition of a simulation. Therefore; qualification and development testing activities were not considered simulations in this study.

Area of Contractor Responsibility - Simulations to support systems engineering and integration are limited to areas considered to be direct responsibility of prime vehicle contractor and NASA centers concerned with Booster and Orbiter vehicle development, core avionics development, mission operations and training tasks. Simulations required for development of main engines by the engine contractor and major vendor items such as air breathing engines are not included in this study. Certain operational engine simulation programs for propulsion systems studies and vehicle systems integration are required and these programs are assumed to be provided by the engine contractor. Required availability dates for these simulation programs are indicated in the appropriate SRD's. Detailed engine simulation programs are required for the following examples of simulations;

Booster Feed System/Engine Interface (SRD 5.1.1.1.4), Booster Structural/Propulsion Stability (SRD 3.2.3.1), Booster Software/Hardware Validation (SRD 6.1.1.1). In many cases it is desirable for vendors to provide math models of subsystem components that may be integrated into systems simulation packages. These math models should be identified and should be contractual requirements of the vendor sub-contractor.

Screening Process - Two basic sources, written documentation and McDonnell Douglas Astronautics Company Space Shuttle engineering and management personnel, were utilized in gathering and evaluating candidate analyses and studies requiring simulation.

Written documentation from manned spacecraft development programs (Gemini, Apollo and Skylab) and military and commercial aircraft development programs was reviewed to identify analyses and studies using simulation techniques. These analyses and studies directly related to the Space Shuttle development needs were considered as candidate SRD's.

Prime source of candidate analyses and studies requiring simulation was the Space Shuttle Phase B project engineering personnel. Since the simulation planning study team was staffed by resident personnel from MDAC Eastern and Western divisions, face to face interviews were conducted with key people from each discipline assigned to both Booster and Orbiter engineering teams.

A preliminary list of 168 candidate Simulation Requirements Descriptions was derived from these discussions. Project personnel that were interviewed drew on experience from past programs and anticipated vehicle design problems in providing inputs to the study team. The preliminary list consisting of candidate SRD's was screened by applying previously discussed criteria. Duplications of candidate SRD's were found when comparing inputs from project personnel in related areas (e.g., POGO analysis was discussed in both structural and propulsion areas). By eliminating these duplications and by application of established criteria, the number of candidate SRD's was reduced to a total of 149. Detailed SRD's were prepared from this list of candidate simulations. Review of the completed drafts of SRD's revealed additional duplicity of simulation requirements, and questionable tasks defined as simulations. A further reduction of SRD's was accomplished by the process of combination and elimination. Combination of SRD's was found feasible in some areas (e.g., propulsion) because of the interrelated nature of multiple

problems requiring simultaneous solution through simulation. The final list of SRD's displayed as a matrix of Booster and Orbiter simulation tasks by interfacing area is shown in Figure 3.1.1-1.

3.1.2 Prepare Simulation Requirements Descriptions (SRD's).- The first step in preparation of an SRD was to prepare statements of objectives and justifications. At this point, the SRD was reviewed with cognizant project personnel for verification of feasibility of the simulation task. The second and final step consisted of preparing a description of the simulation activity and attaching facility and scheduling data. The body of an SRD as defined by this study is separated into five major headings:

(1) Objective
(2) Justification
(3) Description
(4) Facility
(5) Schedule

Objective - The objective is a brief statement defining what task the simulation will accomplish and what outputs are to be expected (e.g., evaluation of flying qualities; development of procedures; definition of software requirements). The objective provides a concise overview of the problem addressed by the simulation and the results desired.

Justification - The justification is a brief statement of technical or cost saving reasons for using simulation to solve the problem defined in the objective section. Justification of the SRD should include answers to the following questions:

- Is simulation the best way to obtain desired results?
- What is effect if simulation is not performed?
- Has this type of simulation proven worthwhile on previous projects?
- How is program cost affected by this simulation?

Description - This section of the SRD provides details concerning inputs to the simulation and methods of implementing the simulation. Inputs consist of data from other analyses required to perform the simulation. Examples of inputs are wind tunnel data, data from other simulations, and development test data. Methods of implementation describe the simulation in terms of:

- Technical problems associated with performance of the simulation

BOOSTER AND ORBITER SIMULATION TASKS

FOLDOUT FRAME 1

FOLDOUT FRAME 2

MAN/MACHINE	MAN/DYNAMIC	MACHINE/DYNAMIC	VEHICLE/SUBSYSTEM	SUBSYSTEM/SUBSYSTEM	HARDWARE/SOFTWARE	SOFTWARE/SOFTWARE	VEHICLE/OPERATIONS
1.1 Engineering 1.1.1 GN&C 1.1.1.1 Booster 1. Man-in-loop Design Verif. 2. Man-in-loop Functional 3. Manned Backup Boost Cont. 1.1.1.2 Orbiter 1. Man-in-loop Design Verif. 2. Man-in-loop Functional 3. Docking Proc. Des. Anal. 1.1.2 Crew Computer Interface 1.1.2.1 Booster 1. C/C Interface Des. Eval. 1.1.2.2 Orbiter 1. C/C Interface Des. Eval. 1.1.3 Controls & Displays 1.1.3.1 Booster 1. D&C Des. Verification 2. Visual & Auditory Warn. System 1.1.3.2 Orbiter 1. D&C Design Verification 2. Visual & Auditory Warn. System 1.1.4 Cargo Handling 1.1.4.1 Orbiter 1. Sat. Placement/Retrieval Development 1.1.5 Crew Station 1.1.5.1 Booster 1. Crew Sta. Soft Mockup 2. Crew Sys. (1-'g') Mockup 1.1.5.2 Orbiter 1. Crew Sta. Soft Mockup 2. Crew Sys. (1-'g') Mockup 1.1.6 Human Factors 1.1.6.1 Booster 1. Workload Analysis 2. Workload Verification 3. Procedures Development 1.1.6.2 Orbiter 1. Workload Analysis 2. Workload Verification 3. Procedures Development 1.2 Training 1.2.1 Booster Flight Crew 1. One-'g' Train Sim. 2. F.B. Procedures Trn. Sim. 1.2.2 Orbiter Flight Crew 1. One-'g' Training Sim. 2. F.B. Procedures Trn. Sim. 1.2.3 Booster & Orbiter 1. Mission Training Sim. 1.2.4 Orbiter Cargo Handling 1. Payload Device Mockup 1.2.5 Ground Controller 1. Mission Training	2.1 Engineering 2.1.1 GN&C 2.1.1.1 Booster 1. Variable Stab. A/C Flt Sim 2. Ascent Environ. Sim. 2.1.1.2 Orbiter 1. Ascent Environ. Sim. 2. Variable Stab. A/C Flt Sim 2.2 Training 2.2.1 Booster Flight Crew 1. High 'g' Training Sim. 2. N.B. Procedures Trn. Sim. 3. In-flight Training Sim. 2.2.2 Orbiter Flight Crew 1. Zero-'g' Accom & Mobility 2. Neutral Buoyancy Mobility 3. N.B. Procedures Trn. Sim. 4. In-flight Training Sim. 5. Docking Procedures Trn. 6. High 'g' Training Sim. 2.2.3 Orbiter Cargo Handling 1. Zero-'g' Accom & Mobility 2. Neutral Buoyancy Mobility	3.1 Flight Mechanics 3.1.1 Booster 1. Ascent/Abort Flyback 2. Term. Transition Sim. 3. Approach, Land, Go-around 4. Flt Test Support Sim. 5. Ferry Mission Sim. 3.1.2 Orbiter 1. Ascent Trajectory Sim. 2. Ascent/Abort Flyback 3. Reentry Trajectory Sim. 4. Term. Transition Sim. 5. Approach, Land, Go-around 6. Ferry Mission Sim. 7. Flt. Test Support Sim. 3.1.3 Combined B&O 1. Separation Simulation 2. Ascent Trajectory 3. Engine Out Trajectory 3.2 Structural Dynamics 3.2.1 Booster 1. Vibration Spectral Resp. 2. Aeroelastic Stability 3. Elastic Vehicle Control 4. Transient Response of Veh. 3.2.2 Orbiter 1. Vibration Spectral Resp. 2. Aeroelastic Stability 3. Structural/Prop. Stab. 4. Elastic Vehicle Control 5. Vehicle Control/POGO 6. Transient Response of Veh. 3.2.3 Combined B&O 1. Structural/Prop Stability 2. Vehicle Control/Struct. 3. Vehicle Control/POGO 4. Transient Response of Veh.	4.1 GN&C System 4.1.1 Booster 1. Control System Sim. 2. Navigation System Sim. 3. Guidance & Targeting 4. Closed Loop Performance 4.1.2 Orbiter 1. Control System 2. Navigation System 3. Guidance & Targeting 4. Closed Loop Performance 4.2 Landing System 4.2.1 Booster 1. Landing Systems Analysis 4.2.2 Orbiter 1. Landing Systems Analysis 4.3 Thermal Protection System 4.3.1 Booster 1. Vehicle Thermal Analysis 4.3.2 Orbiter 1. Vehicle Thermal Analysis	5.1 Propulsion 5.1.1 Main 5.1.1.1 Booster 1. Thrust Buildup 2. Pneumatic Cont. System 3. Propellant Dumping 4. Feed Sys/Engine Interact 5. Propellant Tank Drain 5.1.1.2 Orbiter 1. Feed Sys/Engine Interact 2. Pneumatic Control System 3. Propellant Tank Drain 5.1.2 ACPS/OMS 5.1.2.1 Booster 1. ACPS Engine/Fuel Delivery 2. ACPS Fuel Cond/Feed Syst 5.1.2.2 Orbiter 1. ACPS Fuel Cond/Feed Syst 2. ACPS Engine/Fuel Delivery 3. OMS Engine/Propel. Deliv. 4. ACPS/OMS Start Tank 5.1.3 ABES 5.1.3.1 Booster 1. Jet Flap Sim. 5.2 Avionics 5.2.1 Data Management System 5.2.1.1 Booster 1. DMS System Breadboard 5.2.1.2 Orbiter 1. DMS System Breadboard 5.2.2 Flight Control System 5.2.2.1 Booster 1. TVC System Sim 2. FCS/Hydr. Syst. Interface 3. TVC/Hydr. Syst. Interface 5.2.2.2 Orbiter 1. FCS/Hydr. Syst. Interface 2. TVC/Hydr. Syst. Interface 5.2.3 Guidance & Navigation 5.2.3.1 Booster 1. Autopilot Avionics 5.2.3.2 Orbiter 1. Autoland Avionics 2. Autopilot Avionics 5.3 Crew Systems 5.3.1 ECLS 5.3.1.1 Booster 1. ECLS System Sim. 5.3.1.2 Orbiter 1. ECLS System Sim. 5.4 Power Group 5.4.1 Electrical Power 5.4.1.1 Booster 1. D.C. Elect. Distr. Sys. 5.4.1.2 Orbiter 1. D.C. Elect. Distr. Sys. 5.4.2 Hydraulics 5.4.2.1 Booster 1. Hydr. Syst. Sim. 2. Hydr. Syst. Verification 5.4.2.2 Orbiter 1. Hydr. Syst. Sim. 2. Hydr. Syst. Verification	6.1 Avionics Software 6.1.1 Booster 1. Software/Hardware Valid 6.1.2 Orbiter 1. Software/Hardware Valid	7.1 Avionics 7.1.1 Booster 1. Functional Software Sim. 2. Flight Software Verif. 7.1.2 Orbiter 1. Functional Software Sim. 2. Flight Software Verif.	8.1 Booster 1. Ground Checkout Interface Verification 2. Supportability Sim. 8.2 Orbiter 1. Ground Checkout Interface Verification 2. Supportability Sim. 8.3 Combined Booster & Orbiter 1. Mission Ops. Analysis 2. Fuel Loading Sim.

FIGURE 3.1.1-1

- Systems and/or environments to be math modeled
- Software descriptions in terms of:
  - Special computer capacity requirements
  - Special programming language requirements
  - Special programs and/or routines
  - Existing programs available for use
- Hardware descriptions in terms of:
  - Computer interface requirements
  - Actual vehicle systems hardware required
  - Simulated vehicle systems hardware required

Facility - This section provides a brief statement of the generic facility type required to perform the simulation. In some cases a more detailed description of the facility is given to serve as a general specification of facility requirements. In arriving at facility descriptions, eleven generic types have been identified for the Booster and sixteen for the Orbiter. These types are listed in Figure 3.1.2-1.

Schedule - Simulation schedules indicate the major task milestones including:

- Facility buildup - Consists of a gross schedule for preparing the facility for use. Shows schedule for design, fabrication, and checkout activities.
- Math modeling and programming - Shows time allotted for preparing math models, coding, and debugging.
- Need dates for special input data - Indicates input data requirements that may be critical to completion of simulation task.
- Integrated hardware/software checkout - Indicates time allotted for integration of computer simulation with hardware (e.g., crew station).
- Simulation run times - Actual time span for which the facility is required to meet simulation run schedule.

The activities, based on the Phase C/D program milestones, are included in graphic form on each SRD showing gross milestones of the total simulation task.

Each simulation has been analyzed to determine whether it is required as an engineering development tool or as a training aid and at what stage of Phase C/D vehicle development it is required to provide timely solutions to engineering and training problems.

FIGURE 3.1.2-1
SIMULATION FACILITY REQUIREMENTS

BOOSTER	ORBITER
1. Engineering Crew Station Simulator	1. Engineering Crew Station Simulator
2. Crew Station Soft Mockup	2. Engineering Docking Station Simulator
3. Crew Station Hard Mockup	3. Crew Station Soft Mockup
4. Medium Fidelity Procedures Trainer (Fixed Base)	4. Crew Station Hard Mockup
5. High Fidelity Mission Trainer (Fixed Base)	5. Payload Device Mockups
6. Centrifuge with Crew Station Simulator	6. Medium Fidelity Procedures Trainer (Fixed Base)
7. Medium Fidelity Procedures Trainer (Motion Base)	7. High Fidelity Mission Trainer (Fixed Base)
8. Variable Stability Aircraft	8. Centrifuge with Crew Station Simulator
9. Propellant Handling Facility	9. Zero-"g" Aircraft
10. Systems Integration Laboratory Data Management System Breadboard Avionics System Test Unit Hydraulics and Control Systems Test Unit Crew Station Simulator	10. Neutral Buoyancy Facility
11. General Purpose Computer	11. Docking Procedures Trainer (Motion Base)
	12. Medium Fidelity Procedures Trainer (Motion Base)
	13. Variable Stability Aircraft
	14. Propellant Handling Facility
	15. Systems Integration Laboratory Data Management System Breadboard Avionics Systems Test Unit Hydraulics and Control Systems Test Unit Crew Station Simulator
	16. General Purpose Computer

3.2 Task II - Develop Integrated Plan

The objective of this task was to integrate individual SRD's into a master simulation plan and coordinate the master plan with Space Shuttle Phase C/D vehicle development plan. During integration phase, two alternatives to the master plan were developed to bracket the range of recommended simulation support for systems engineering and integration.

Plan I - Technical risk is minimized by this plan. Deepest possible technical penetration is accomplished using multiple simulation activities in NASA and industry in areas essential to major design goals. The major integration task entailed scheduling of simulation tasks in proper phase with the Space Shuttle vehicle program development so that maximum technical value may be achieved. Facility and hardware requirements were based on accomplishing the task within the confines of the schedule. Potential conflicts due to facility overloads were eliminated by increasing the number of facilities used or expanding a single facility. Cost considerations were not allowed to compromise the technical objectives of the simulation requirements.

Plan II - This plan contains simulation tasks to achieve adequate technical penetration to support only critical design and integration areas. Simulations not considered critical were deleted or combined with others. Justifications given in SRD's were used to guide priority decisions. Construction of new facilities may be deferred in favor of modification and use of existing facilities. Costs had considerable impact on decisions concerning technical penetration, scheduling, and facility use, and are a major controlling factor in this plan. The technical risk related to this alternative is higher than that of Plan I.

The approach in defining two alternate plans and developing their attendant rationales included the following considerations:

(1) Technical penetration/risk
(2) Generic facilities, hardware requirements
(3) Potential conflicts due to facility overloads
(4) Multiple simulations to ensure adequate technical penetration and monitoring capability
(5) Costs

Technical Penetration/Risk - In formulating individual SRD's, a number of technical problems were defined. These problems have several methods of solution representing various degrees of technical penetration and attendant risk. Maximizing technical penetration through simulation techniques was accomplished in this study by three methods:

(1) Iterative simulations
(2) Integrated hardware/software simulations
(3) Multiple simulations

Iterative simulations involve the improvement of math models and rerunning of simulations as input data becomes better defined or modeling techniques are improved. This aspect of technical penetration is difficult to plan and is generally implemented through decision making based on the day-to-day situation. Simulations that generally fall into this classification are all-digital computer studies such as simulations to support structural dynamics and vehicle subsystems design and analyses.

Integrated hardware/software simulations utilize the concept of improving accuracy of simulation through substitution of increased amounts of actual hardware in place of computer math models. The result is improved fidelity of simulation with subsequent improvement in definition of the subsystem interface under study. This aspect of simulation may be planned and the resulting penalties in terms of cost due to increasing complexity may be accurately estimated. The expected results of performing such simulations may be assessed by drawing on experience from past simulation programs used to support hardware development. Typical simulations identified in this plan which employ the hardware/software concept are high-fidelity man-in-the-loop functional simulations (SRD 1.1.1.1.2) and software/hardware validation simulations (SRD 6.1.1.1) employing the systems integration laboratory facility.

Multiple simulation involves correlating results of systems development through similar independent simulations performed by NASA and contractor in separate facilities. This effort will be discussed in detail in a later section.

Generic Facilities, Hardware Requirements - Individual Simulation Requirements Descriptions identify generic facilities required to perform various simulation tasks. General descriptions of the facilities are recorded in the applicable SRD's and appendices D and E. A total of eleven Booster and sixteen Orbiter

generic facilities shown in Figure 3.1.2-1 are required to perform the simulations presented in this plan.

Surveys of industry simulation facilities indicate many facilities are available for use at various locations throughout industry and NASA.

Consideration should be given to the modification and use of those facilities in lieu of constructing new facilities for the Space Shuttle simulation program. Major points to be considered in the decision to modify or build new facilities include:

(1) Non-recurring cost of building versus modification of existing facilities.

(2) Projected operating costs of new versus existing facilities.

(3) Adequacy of existing facilities to perform simulation functions.

(4) Accessibility of proposed facility.

(5) Total life requirements of facility.

Additional detailed technical and cost data is required to make final decisions concerning new versus modified simulation facilities. For purposes of this study, decisions concerning utilization of facilities and the assignment of responsibility for facilities to the center or contractor were based heavily on past programs.

<u>Potential Conflicts Due to Facility Overload</u> - A master schedule of all SRD's by facility was generated to show individual time spans of facility occupancy and starting dates of each SRD. These schedules were based on individual SRD requirements and the interrelation between SRD's. Booster and Orbiter master simulation schedules are shown in Figures 3.2.1-1 and 3.2.1-2. These master schedules represent all SRD's included in Plan I, the minimum risk maximum technical penetration plan. Plan I schedule presents the worst case condition in terms of potential facility overload. If schedule conflicts can be resolved on this plan any lesser alternative should constitute a workable plan. Time durations of individual scheduled simulation activities represent projected facility occupancy times, or simulation run times. All schedules shown on individual SRD's (Appendix A) indicate, in addition to simulation run times, activities required to prepare for simulation runs.

The process of manually resolving scheduling conflicts represented a formidable problem in some cases (e.g., the Orbiter engineering crew station simulator is

FOLDOUT FRAME 1

BOOSTER VEHICLE MASTER SIMULATION SCHEDULE

FOLDOUT FRAME 2

BOOSTER

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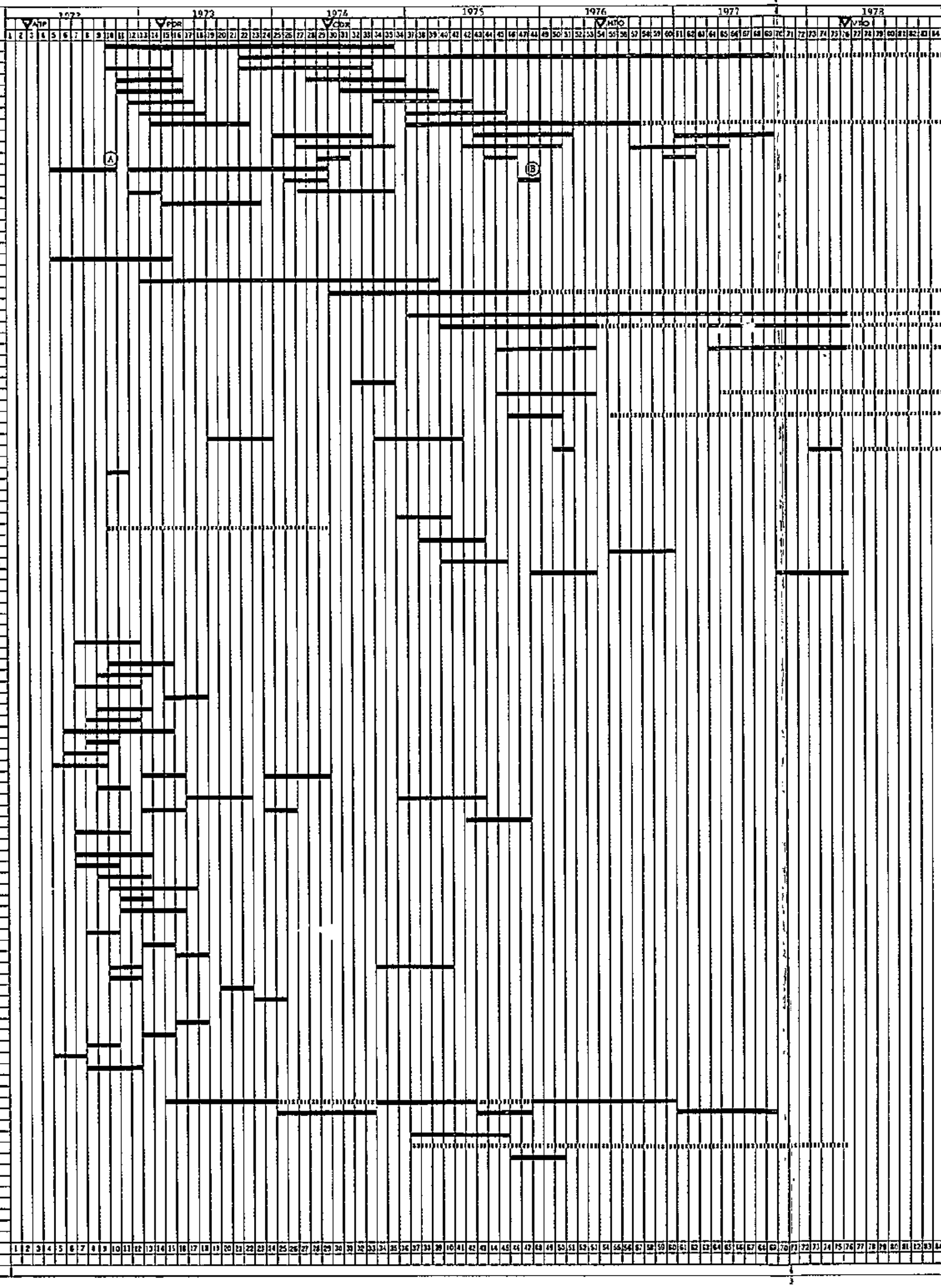
MASTER SCHEDULE

		ACTIVITY	
①	1	MAN-IN-LOOP G&C DESIGN VERIFICATION	1.1.1.1.1
①	2	MAN-IN-LOOP PROC DEVEL & FUNCTIONAL	1.1.1.1.2
①	3	DIGITAL AUTOPILOT	
①	4	LAUNCH	
①	5	SEPARATION	
①	6	ENTRY & TRANSITION	
①	7	APPROACH & LANDING	
①	8	TOTAL MISSION	
①	9	CHECKOUT	
①	10	ABORTS	
①	11	MANNED BACKUP BOOSTER CONTROL	1.1.1.1.3
①	12	CREW-COMPUTER INTERFACE DESIGN EVALUATION	1.1.2.1.1
①	13	CREW STATION D&C DESIGN VERIFICATION	1.1.3.1.1
①	14	VISUAL & AUDITORY WARNING SYSTEM	1.1.3.1.2
①	15	WORKLOAD HUMAN FACTORS EVALUATION	1.1.6.1.2
①	16		
①	17		
①	18		
①	19		
②	20	CREW STATION SOFT MOCKUP GEOM. VERIFICATION	1.1.5.1.1
②	21		
③	22	CREW SYSTEMS (ONE 'g') MOCKUP	1.1.5.1.2
③	23	ONE 'g' FAMILIARIZATION TRAINING SIM.	1.2.1.1
③	24		
④	25	CREW MISSION PROCEDURES DEVELOPMENT	1.1.6.1.3
④	26	PROCEDURES TRAINING SIM	1.2.1.2
④	27		
⑤	28	MISSION TRAINING SIM. (B&O)	1.2.3.1
⑤	29		
⑤	30		
⑥	31	ENVIRONMENTAL SIM ASCENT & REENTRY	2.1.1.1.2
⑥	32	HIGH - 'g' TRAINING SIM	2.2.1.1
⑦	33		
⑦	34	MOTION BASE FLIGHT TRAINING SIM	2.2 1 2
⑦	35		
⑧	36	VARIABLE STABILITY A/C FLIGHT SIM.	2.1 1.1.1
⑧	37	IN-FLIGHT TRAINING SIM	2.2 1 3
⑨	38		
⑨	39	PROPELLANT TANK DRAINAGE MODEL	5.1.1 1.5
⑨	40		
⑩	41		
⑩	42		
⑩	43	HYDRAULIC SUBSYSTEM VERIFICATION	5.4.2 1.2
⑩	44	DATA MANAGEMENT SYSTEM BREADBOARD EVAL	5.2.1 1.1
⑩	45	FCS/HYDR SYSTEM INTERFACE VERIFICATION	5.2.2.1.2
⑩	46	TVC/HYDR SYSTEM INTERFACE VERIFICATION	5.2.2.1.3
⑩	47	AUTOPILOT FUNCTIONAL VERIFICATION	5.2.3.1.1
⑩	48	SOFTWARE/HARDWARE VALIDATION	6.1.1.1
⑩	49		
⑩	50		
⑩	51		
⑩	52		
⑩	53		
⑪	54	WORKLOAD ANALYSIS	1.1.6.1.1
⑪	55		
⑪	56	ASCENT/ABORT FLYBACK TRAJECTORY	3.1.1.1
⑪	57	THEORETICAL TERM. TRANSITION	3.1.1.2
⑪	58	APPROACH AND LANDING	3.1.1.3
⑪	59	FLIGHT TEST SUPPORT	3 1.1.4
⑪	60	FERRY MISSION SIM	3.1 1.5
⑪	61	SEPARATION SIM	3 1.3.1
⑪	62	ASCENT TRAJECTORY	3.1.3.2
⑪	63	ENGINE OUT TRAJECTORY	3 1.3.3
⑪	64	VIBRATION SPECTRA	3.2.1.1
⑪	65	AEROELASTIC STABILITY	3.2.1.2
⑪	66	ELASTIC VEHICLE/CONTROL SURFACE	3 2 1.3
⑪	67	TRANSIENT RESPONSE OF VEHICLE	3.2.1.4
⑪	68	STRUCTURAL-PROPULSION STABILITY	3.2.3.1
⑪	69	VEHICLE CONTROL/STRUCT.	3.2.3.2
⑪	70	VEHICLE CONTROL/POGO	3.2.3.3
⑪	71	TRANSIENT RESPONSE OF VEHICLE	3.2.3.4
⑪	72		
⑪	73	CONTROL SYSTEM SIM.	4.1.1.1
⑪	74	NAVIGATION SYSTEM SIM.	4.1.1.2
⑪	75	GUIDANCE & TARGETING SIM	4.1.1.3
⑪	76	CLOSED LOOP G&C PERFORMANCE	4 1 1.4
⑪	77	LANDING SYSTEM ANALYSIS	4 2.1.1
⑪	78	VEHICLE THERMAL ANALYSIS	4.3 1.1
⑪	79		
⑪	80	THRUST BUILDUP	5.1.1 1.1
⑪	81	PNEUMATIC CONTROL SYSTEM	5.1 1.1 2
⑪	82	PROPELLANT DUMPING	5.1 1.1 3
⑪	83	FEED SYSTEM/ENGINE INTERFACE	5.1.1.1.4
⑪	84		
⑪	85	ACPS ENGINE FUEL DELIVERY	5 1.2.1.1
⑪	86	ACPS FUEL COND./FEED SYSTEM	5.1 2.1 2
⑪	87		
⑪	88	JET FLAPS CONTROL SIM	5.1 3.1 1
⑪	89	TVC SYSTEM SIM.	5.2 2.1.1
⑪	90	ECLS SYSTEM SIM.	5.3 1.1 1
⑪	91	D.C. ELECT DISTR SYSTEM ANAL.	5.4.1.1 1
⑪	92	HYDRAULIC SYSTEM SIM	5.4.2.1 1
⑪	93		
⑪	94		
⑪	95	FUNCTIONAL SOFTWARE SIM.	7.1.1.1
⑪	96	FLIGHT SOFTWARE VERIFICATION	7.1.1.2
⑪	97		
⑪	98	GROUND CHECKOUT INTERFACE	8.1.1
⑪	99	SUPPORTABILITY ANALYSIS	8.1.2
⑪	100	FUEL LOADING PROCESS MANAGEMENT	8.3.4
	101		
	102		
	103		
	104		
	105		
	106		
	107		
		MONTHS AFTER GO AHEAD	
		CALENDAR	



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BASIS

DEPT 35 ESTIMATE NO.______
ENGINEERING______ HRS/WK______ SHIFTS
TOOLING______ HRS/WK______ SHIFTS
PRODUCTION______ HRS/WK______ SHIFTS

NOTES

① ENGINEERING CREW STATION SIM
② SOFT CREW STATION MOCKUP
③ HARD CREW STATION MOCKUP
④ MEDIUM FIDELITY PROCEDURES TRNR (F.B.)
⑤ HIGH FIDELITY B&O MISSION SIM.
⑥ CENTRIFUGE W/CREW STATION
⑦ M.B. MED FIDELITY PROCEDURES SIM.
⑧ VARIABLE STABILITY AIRCRAFT
⑨ PROPELLANT HANDLING FACILITY
⑩ SYSTEMS INTEGRATION LAB
DMS BREADBOARD
ASTU
HCTU
CREW STATION ①
⑪ COMPUTER

Ⓐ DONE IN COMPUTER FACILITY
Ⓑ DONE IN SIL FACILITY

REFERENCE

COORDINATION

ENGINEERING______
PROCUREMENT______
MANUFACTURING______
FLIGHT______

PREPARED BY H. H. Schramm
ISSUED BY______ DATE 19 July 71

FIGURE 3.2.1-1

FOLDOUT FRAME 1

ORBITER VEHICLE MASTER SIMULATION SCHEDULE

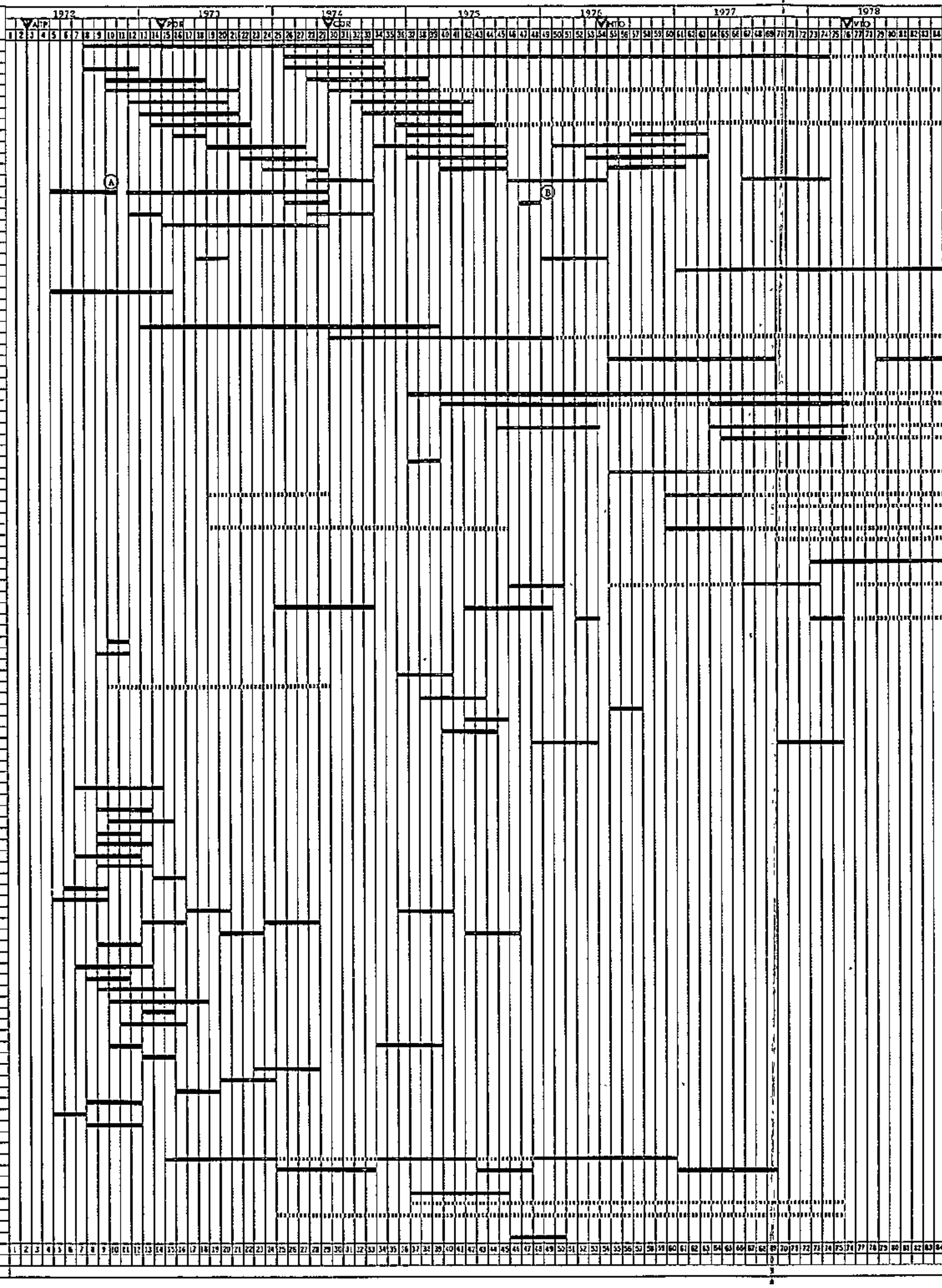
FOLDOUT FRAME 2

ORBITER

MCDONNELL DOUGLAS CORPORATION

MASTER SCHEDULE

Facility	No.	ACTIVITY	
(1)	1	MAN-IN-LOOP GN&C DESIGN VERIFICATION	1.1 1.2 1
	2	MAN-IN-LOOP PROC DEV. & FUNCTIONAL	1.1.1.2 2
	3	DIGITAL AUTOPILOT SUBSYSTEM	
	4	NAVIGATION	
	5	RENDEZVOUS	
	6	ENTRY	
	7	APPROACH & LANDING	
	8	RETURN FROM ORBIT	
	9	ON ORBIT	
	10	CHECKOUT	
	11	LAUNCH	
	12	INSERTION	
	13	ABORTS	
	14	CREW-COMPUTER INTERFACE DESIGN EVALUATION	1.1.2 2.1
	15	CREW STATION D&C DESIGN VERIFICATION	1.1.3.2.1
	16	VISUAL & AUDITORY WARNING SYSTEM	1.1.3.2.2
	17	WORKLOAD HUMAN FACTORS EVALUATION	1.1.6.2.2
	18		
	19		
(2)	20	DOCKING PROCEDURES-DESIGN ANALYSIS	1.1.1.2.3
	21	SATELLITE PLACEMENT DEVICE DEVELOPMENT	1.1.4.1.1
	22		
(3)	23	CREW STATION SOFT MOCKUP CTON. VERIFICATION	1.1.5.2.1
	24		
	25		
(4)	26	CREW SYSTEMS (ONE-'g')MOCKUP	1 1.5.2 2
	27	ONE 'g' FAMILIARIZATION TRAINING SIM	1.2.2.1
	28		
(5)	29	PAYLOAD DEVICE MOCKUPS	1.2 4.1
	30		
	31		
(6)	32	CREW MISSION PROCEDURES DEVELOPMENT	1.1.6.2.3
	33	PROCEDURES TRAINING SIM	1.2.2.2
	34		
(7)	35	MISSION TRAINING SIM (B/O)	1.2 3 1
	36	GROUND CONTROLLER TRAINING SIM.	1.2 5.1
	37		
(8)	38	ENVIRONMENTAL SIM ASCENT & REENTRY	2.1 1.2.1
	39	HIGH 'g' TRAINING SIM	2.2 2.6
	40		
(9)	41	ZERO 'g' FAM & TRAINING SIM	2.2.2.1
	42	ZERO 'g' FAM & TRAINING-CARGO HANDLER	2.2 3.1
	43		
(10)	44	NEUTRAL BOUYANCY MOBILITY TRAINING SIM	2.2 2.2
	45	NEUTRAL BOUY. MOB. TRAIN.-CARGO HANDLER	2 2.3 2
	46		
(11)	47	FULL SCALE DOCKING PROCEDURES TRAIN	2.2.2 5
	48		
(12)	49	MOTION BASE FLIGHT TRAINING SIM	2 2.2.3
	50		
(13)	51	VARIABLE STAB. A/C FLIGHT SIM	2.1.1 2.2
	52	IN FLIGHT TRAINING SIM	2.2.2 4
	53		
(14)	54	PROPELLANT TANK DRAINAGE MODEL	5 1.1.2 3
	55	ACPS/OMS START TANK BREADBOARD	5.1.2.2 4
	56		
(15)	57	HYDRAULIC SUBSYSTEM VERIFICATION	5.4.2 2.2
	58	DATA MANAGEMENT SUBSYSTEM BREADBOARD EVAL.	5 2.1.2.1
	59	FCS/HYDR SYSTEM INTERFACE VERIF.	5.2.2.2.1
	60	TVC/HYDR SYSTEM INTERFACE VERIF.	5.2 2.2.2
	61	AUTOLAND FUNCTIONAL VERIFICATION	5.2.3 2.1
	62	AUTOPILOT FUNCTIONAL VERIFICATION	5.2.3 2.2
	63	SOFTWARE/HARDWARE VALIDATION	5.1 2.1
	64		
	65		
	66		
(16)	67	WORKLOAD ANALYSIS	1.1.6.2.1
	68		
	69	ASCENT TRAJECTORY	3.1.2.1
	70	ASCENT/ABORT FLYBACK TRAJECTORY	3.1.2.2
	71	REENTRY TRAJECTORY	3.1.2.3
	72	THEORETICAL TERM TRANSITION	3.1.2.4
	73	THEO APPROACH AND LANDING	3.1.2.5
	74	THEORETICAL FERRY MISSION	3.1.2.6
	75	FLIGHT TEST SUPPORT	3.1.2.7
	76	VIBRATION SPECTRA	3 2.2.1
	77	AEROLASTIC STABILITY	3.2.2.2
	78	STRUCTURAL-PROPULSION STABILITY	3.2.2.3
	79	ELASTIC VEHICLE/CONTROL SURFACE	3.2.2.4
	80	VEHICLE CONTROL/POGO	3 2.2.5
	81	TRANSIENT RESPONSE OF VEHICLE	3.2.2.6
	82		
	83	CONTROL SYSTEM SIM.	4.1.2.1
	84	NAVIGATION SYSTEM SIM.	4.1.2.2
	85	GUIDANCE AND TARGETING SIM.	4.1.2.3
	86	CLOSED LOOP GN&C PERFORMANCE	4.1.2.4
	87	LANDING SYSTEM ANALYSIS	4.2.2.1
	88	VEHICLE THERMAL ANALYSIS	4.3.2.1
	89		
	90	FEED SYSTEM/ENGINE INTERFACE	5.1.1.2.1
	91	PNEUMATIC CONTROL SYSTEM	5.1.1.2 2
	92	ACPS FUEL COND/FEED SYSTEM	5.1 2.2 1
	93	ACPS ENGINE FUEL DELIVERY	5 1.2.2 2
	94	OMS ENGINE PROPELLANT DELIVERY	5 1 2.2 3
	95	ECLS SYSTEM SIM	5.3.1.2 1
	96	D.C. ELECTRICAL DISTR SYSTEM ANAL	5 4.1.2 1
	97	HYDRAULIC SYSTEM SIM.	5 4 2.2 1
	98		
	99		
	100	FUNCTIONAL SOFTWARE SIM.	7.1.2.1
	101	FLIGHT SOFTWARE VERIFICATION	7.1.2.2
	102		
	103	GROUND CHECKOUT INTERFACE	8 2.1
	104	SUPPORTABILITY ANALYSIS	8.2.2
	105	MISSION OPERATIONS ANALYSIS	8 3 1
	106		
	107	FUEL LOADING PROCESS MANAGEMENT	8.3.2
		MONTHS AFTER GO AHEAD	
		CALENDAR	



NOTES

(1) ENGINEERING CREW STATION SIM.
(2) ENGINEERING DOCKING STA. SIM.
(3) SOFT CREW STATION MOCKUP
(4) HARD CREW STATION MOCKUP
(5) PAYLOAD DEVICE MOCKUPS
(6) MEDIUM FIDELITY PROCEDURES TRNR (F.B.)
(7) HIGH FIDELITY B&O MISSION SIM.
(8) CENTRIFUGE W/CREW STATION
(9) ZERO - "G" AIRCRAFT
(10) NEUTRAL BOUYANCY FACILITY
(11) M.B. DOCKING PROC. TRAINER
(12) M.B. MED-FIDELITY PROCEDURES SIM.
(13) VARIABLE STABILITY AIRCRAFT
(14) PROPELLANT HANDLING FACILITY
(15) SYSTEMS INTEGRATION LAB
BREADBOARD DMS
ASTU
LCTU
CREW STA (1)
(16) COMPUTER

(A) DONE IN COMPUTER FACILITY
(B) DONE IN SIL FACILITY

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BASIS

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TOOLING ____ HRS/WK ____ SHIFT(S)
PRODUCTION ____ HRS/WK ____ SHIFT(S)

REFERENCE

COORDINATION

ENGINEERING ____
PROCUREMENT ____
MANUFACTURING ____
FLIGHT ____

PREPARED BY ____
ISSUED BY ____ DATE 19 July 1971

close to being overloaded). Later in this study some work was done in applying automated scheduling processes developed by MDAC. The TLGEN computerized timeline generation program uses deterministic techniques to identify schedule conflicts based on assigned priorities allowing subsequent resolution of these conflicts.

Two levels of activity are indicated on the master schedule. Solid lines represent a high level of activity in which the facility is dedicated to a particular simulation, or time shared during the calendar period with a number of simulations. In the case of simulations requiring digital computers only, it is assumed that multiple facilities are available throughout industry and NASA and as a result, no serious overloads are anticipated. More concentrated scheduling efforts will be required during vehicle development program due to increased visibility of the scope of some simulations requiring large-scale computational facilities (e.g., SRD 3.2.3.1 Propulsion/Structural Analysis).

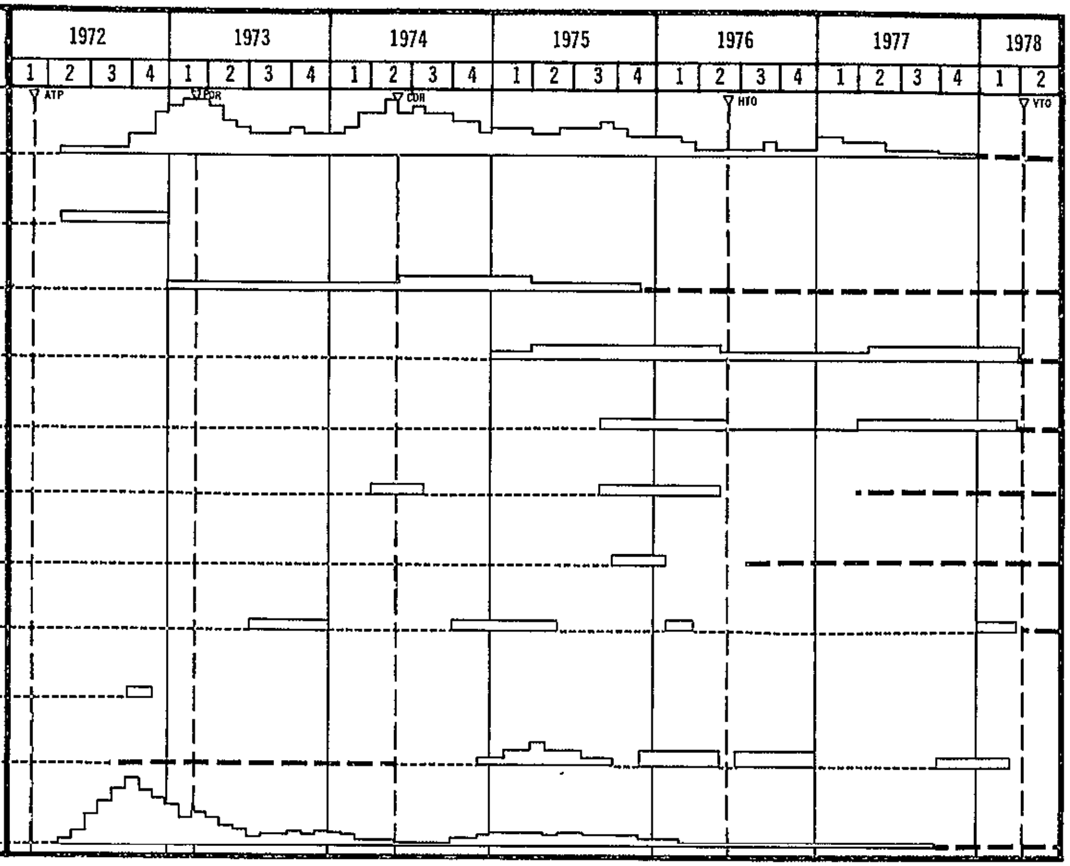
Simulation schedules indicated by broken lines represent a low level of usage in which the facility should be maintained for simulation activity on a standby basis. This condition exists primarily with training and operational support phases late in the program. These requirements may be better defined later in the development program.

Booster and Orbiter facility occupancy rates shown in Figures 3.2.1-3 and 3.2.1-4 provide additional indication of simulation facility usage. Simulation facility usage rates shown are related to time spans of each SRD, and the occupancy hours per day for each simulation task. The minimum occupancy hours per day shown in Figures 3.2.1-3 and 3.2.1-4 represent the value of the minimum step increase in magnitude of facility loading shown on the schedules. These figures indicate graphically which facilities are loaded to the point of presenting potential scheduling problems, and were used to estimate costs based on estimated occupancy rates.

Multiple Simulations to Assure Adequate Penetration and Monitoring Capability - Certain key simulation tasks to be performed during the vehicle design/integration phase are essential to ensure technical penetration and to minimize attendant risk. In order that NASA have adequate monitoring capabilities, recommendations for multiple or dual simulations to be performed by NASA and the contractor are outlined in the simulation plan. For example, the area of crew/computer communication (SRD 1.1.2.1.1) is of sufficient technical importance to the astronauts, human factors personnel, and systems engineers that adequate solution of the problem

BOOSTER FACILITY OCCUPANCY RATES

MINIMUM OCCUPANCY HRS/DAY	ACTIVITY	NUMBER OF SRD'S
2	CREW STATION SIMULATOR	7
N/A	CREW STATION SOFT MOCKUP	1
N/A	CREW STATION HARD MOCKUP	2
8	PROCEDURES TRAINER (FB)	2
8	MISSION TRAINING SIMULATOR	1
8	CENTRIFUGE W/CREW STATION SIM	2
8	MB MEDIUM FIDELITY PROCEDURES	1
8	VARIABLE STABILITY AIRCRAFT	2
8	PROPELLANT HANDLING FACILITY	1
4	SYSTEMS INTEGRATION LABORATORY	6
N/A	GENERAL COMPUTING FACILITIES	38

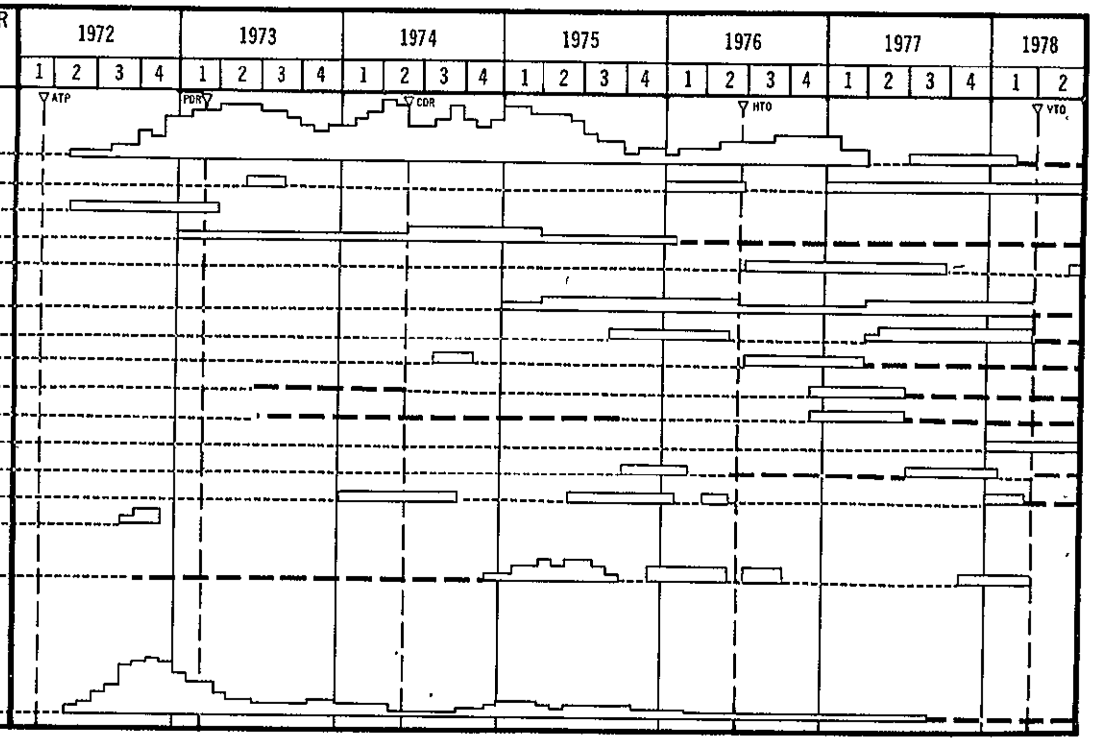


NOTE: VALUE SHOWN. FOR OCCUPANCY RATE EQUALS MINIMUM STEP VALUE

FIGURE 3.2.1-3

ORBITER FACILITY OCCUPANCY RATES

MINIMUM OCCUPANCY HRS/DAY	ACTIVITY	NUMBER OF SRD'S
	ORBITER	
2	CREW STATION SIMULATION	6
8	DOCKING STATION SIMULATION	2
N/A	CREW STATION SOFT MOCKUP	1
N/A	CREW STATION HARD MOCKUP	2
N/A	PAYLOAD DEVICE MOCKUP	1
8	PROCEDURES SIMULATOR (FB)	2
8	HIGH FIDELITY B/O MISSION SIMULATION	2
8	CENTRIFUGE WITH CREW STATION	2
8	ZERO "G" AIRCRAFT	2
8	NEUTRAL BOUYANCY FACILITY	2
8	MB DOCKING PROCEDURES TRAINER	1
8	MB MEDIUM FIDELITY PROCEDURE TRN	1
8	VARIABLE GEOMETRY AIRCRAFT	2
8	PROPELLANT HANDLING FACILITY	2
4	SYSTEMS INTEGRATION LABORATORY	7
N/A	GENERAL PURPOSE COMPUTER FACILITY	34



NOTE: VALUE SHOWN FOR OCCUPANCY RATE EQUALS MINIMUM STEP VALUE

FIGURE 3.2.1-4

can best be achieved by conducting multiple simulation activities in two facilities, those of NASA and the contractor.

Multiple simulation activities do not require similar methods of treatment by NASA and the contractor in terms of degree of technical penetration. This is a reasonable situation provided one of the simulations meet requirements of technical penetration specified by the appropriate SRD. It should be emphasized that attempts to correlate results from simulations using even slightly different techniques often show a disparity and should be treated with caution.

An important aspect of multiple simulations is which simulations, if not done by both NASA and the contractor, should be done individually by one or the other. A guideline may be established by considering the characteristic roles of NASA and the contractor in performance of simulation activities to support program development. Based on functions of program development, four broad types of simulations are required:

(1) Design simulations, used in problem solving during the design and development phase.

(2) Hardware verification simulation, nearly synonymous and, in some cases, exactly synonymous with development integration testing. Simply, the testing or simulations which must be done to establish system confidence prior to first flight.

(3) Crew procedures development and mission planning simulations.

(4) Crew training simulations.

It is expected that the contractor will do a large amount of Design Simulation, and NASA will do a smaller amount. NASA's interest should concentrate on Orbiter/Booster interface and coupled vehicle performance problems while contractors will concentrate mainly on their own vehicle.

It is expected that both NASA and the contractors will be heavily involved in Hardware Verification Simulation, the contractor may refer to this work as "integrated systems test" and consider it a natural part of the development test plan.

Crew procedures development, mission planning and training simulations have historically been primarily NASA responsibility and this is expected to continue.

Cost - Estimated operating costs and non-recurring facility costs were

taken into consideration in developing the integrated simulation plans. Plan I was formulated without regard to simulation cost with technical penetration acting as the driving factor. Essential simulations required for adequate technical penetration were included in Plan II, but with a reduction in duplicity of contractor/center efforts, thus creating a cost reduction from Plan I. Cost estimates were used to evaluate the advisability of simulations that were expected to provide minimal technical value. These simulations were eventually proposed to be eliminated, combined with other simulations, or performed in existing facilities in lieu of providing funds for new facilities.

Cost estimates were also used to arrive at Booster and Orbiter simulation facility cost ratios between Plan I and Plan II. The estimates are rough order of magnitude and are independent of Phase B Space Shuttle cost estimate, which does not identify simulation costs as an integral part of total development costs.

The following rationale was used in arriving at an estimated facility cost for Booster and Orbiter vehicle development.

- Estimates were based on past program costs, quoted facility costs, and Phase B actuals.
- NASA center and contractor costs were assumed to be the same for identical facilities.
- Systems integration laboratory non-recurring costs were pro-rated at 50% of total cost estimate assuming the balance is charged to development test effort.
- Time span of facility use covers period from authority to proceed (ATP) to operational capability (OC).
- High fidelity mission trainer non-recurring costs were divided between Booster and Orbiter estimates.
- The following were assumed to be new facilities:

    Engineering Crew Station Simulator
    Engineering Docking Station Simulator
    Crew Station Soft Mockup
    Crew Station Hard Mockup
    Payload Device Mockups
    Medium Fidelity Procedures Trainer (Fixed Base)
    Propellant Handling Facility
    Systems Integration Laboratory
    High Fidelity Mission Trainer (Fixed Base)

- The following are assumed to be existing facilities modified to serve Space Shuttle simulation needs:

  Zero-"g" Aircraft
  Neutral Buoyancy Facility
  Docking Procedures Trainer (Motion Base)
  Medium Fidelity Procedures Trainer (Motion Base)

- The following are assumed to be existing modified facilities with costs shared equally by Booster and Orbiter:

  Variable Stability Aircraft
  Centrifuge with Crew Station Simulator

- Costs involving use of the general purpose computer as a stand-alone facility were not included in this estimate.

- Facility operating costs are incurred only during occupancy periods shown on the master schedule.

4.0 RESULTS

Results of this study are represented by two alternate simulation plans consisting of integrated Simulation Requirements Descriptions (SRD) to support system engineering/integration activities during phase C/D vehicle development. The alternate plans are based on simulation activities required to support concurrent development of reusable Booster and Orbiter vehicles as outlined by requirements of the Space Shuttle Phase B contract (NAS 8-26016).

4.1 Simulation Requirements Descriptions

The majority of time expended on this study was concentrated on the first task, identification of simulations and preparation of Simulation Requirements Descriptions (SRD's). The SRD's presented in Appendix A represent the input data required to prepare the two alternate simulation plans.

4.2 Integrated Plans

The second task consisted of deriving two alternate simulation plans for the Booster and Orbiter vehicle development by applying individual SRD's to the criteria discussed in Section 3.2. Two resulting alternate plans are presented in summary form in Appendix B. The summary shows, in matrix form, each Booster and Orbiter simulation activity with related generic facility requirements and center/contractor responsibilities for Plan I and Plan II. The attendant rationale used by the study team in deriving the two plans is discussed below.

4.2.1 Booster - Man-in-the-loop simulations (Items 1-7) considered a design verification type simulation would be done by NASA and the contractor in Plan I for maximum technical penetration. In Plan II, only the contractor would perform man-in-the-loop design simulations under close NASA cognizance thereby eliminating the need for a NASA engineering simulation facility. The contractor should retain responsibility for man-in-loop simulations (engineering) in its role of vehicle designer. Certain specialized problem-oriented simulations in Plan II would be combined with planned man-in-loop simulations (Items 1, 2). These specialized simulations include Manned Backup Boost Control (Item 3), Visual and Auditory Warning System (Item 6), and Workload Human Factors Analysis (Item 7). These combinations would represent a cost savings by reducing facility utilization time.

Under Plan II, the soft mockup facility (Item 8) which is used as an early design aid in Plan I, would be eliminated at a small cost savings.

Two crew systems mockups (Items 9, 10) would be available on site to both NASA and contractor in Plan I. Most mockups should be kept current throughout the development phase to provide proper visibility of crew systems configuration. In Plan II, a single crew station is provided and is located at the contractor during early development phase and moved to the cognizant NASA center for training phase. This series arrangement saves the cost of one crew station facility with a resulting lack of complete assessibility of the mockup to both contractor and NASA.

Training simulations have characteristically been the responsibility of NASA, and is reflected in Plan I by Items 11, 12, 13, 15, 16 and 18. Most training facilities are required for both plans to accomplish the total training mission. In either plan possible cost savings may be realized by modifying and using existing facilities. In addition, at least two training simulations may be eliminated for Plan II. (1) High-g training simulation (Item 15) may be eliminated because the general environment of launch and reentry will have little effect on function of the crew. Lack of need for recurrent high-g training during operational phase may be justified by performing some basic training concurrent with engineering man-in-the-loop Ascent & Entry simulations (Item 14). (2) In-flight training is considered too costly for the added fidelity of simulation to be gained over motion base simulators. Therefore, both engineering hardware development and training uses (Items 17 and 18) are eliminated in Plan II.

Hardware verification simulations (Items 20-25) conducted as a part of verification testing using a systems integration laboratory facility are of sufficient importance to vehicle development to warrant parallel contractor and NASA activities as shown in Plan I. This plan gives deep technical penetration at a high facility cost (see description of facility in Appendix E). Plan II calls for cost reduction through limiting verification simulation activities (and facility requirements) to contractor only. Since this simulation activity is tied closely to hardware development, it is primarily a contractor responsibility whether plan I or II is implemented.

The remaining all-digital computer simulations (Items 26-64) are basically design simulations. As such, they are of prime interest to the contractor. In most cases, high technical penetration is indicated in Plan I by combined contractor and NASA activities. The low cost, adequate penetration approach of Plan II indicates simulations to be done by contractor only. Exceptions which

should be noted are listed as follows:

(1) Simulations with objectives primarily for support of vehicle subsystems design are shown in Plan I as being responsibility of the contractor only. Items 35, 47, 48 and 50-59 are included in this category.

(2) Two simulations involving structural/propulsion stability analysis (Items 39, 41) in Plan II would be done by NASA because of experience factor, computing facility requirements, and necessary integration activity between airframe and engine contractors.

(3) Simulations oriented towards similar problems were combined in Plan II. Examples of combinations are shown in Appendix B.

4.2.2 Orbiter - Man-in-the-loop simulations (Items 1-6) may be considered a design verification type simulation and would be done by NASA and the contractor in Plan I for maximum technical penetration. For Plan II, only the contractor would perform man-in-the-loop simulations under close NASA cognizance. This plan eliminates the need for a NASA engineering simulation facility. Certain specialized simulations may combine with man-in-loop GN&C simulations (Items 1 and 2). These simulations are Visual and Auditory Warning System (Item 5) and Workload Human Factors Analysis (Item 6).

Docking procedures development (Item 7) and Satellite Placement Device Development (Item 8) are conducted in Plan I with a special facility representing a crew station mockup of the docking controls and out-the-window displays. Requirements for this facility are eliminated in Plan II by combining docking procedures development with man-in-the-loop GN&C simulations and eliminating satellite placement device development simulation. Both of these simulations provide minimum results and involve the expense of a dedicated facility.

The crew station soft mockup (Item 9) used in Plan I as an early design aid may be eliminated from Plan II at a small cost savings.

Crew systems mockup (Items 10 and 11) would be available on site to both NASA and contractor in Plan I. Both mockups should be kept current throughout the development phase to provide proper visibility of crew systems configuration. In Plan II, a single crew station is provided and is located at the contractor during early development phase and moved to the cognizant NASA center for the training phase. This series utilization saves the cost of one crew station facility consequently causing the lack of complete accessibility to both contractor and NASA.

Payload device mockups (Item 12) are used for dual roles of development support and training in Plan I. These mockups may be eliminated from Plan II at a small cost savings. Procedures development and training simulations have characteristically been the responsibility of NASA and is reflected in Plan I by Items 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24 and 26. Most of the listed training facilities are required for both plans to accomplish the total training mission. It is possible in each plan to realize cost savings by modifying and using existing facilities. Five training simulations are recommended to be eliminated from Plan II.

(1) High-g training simulation (Item 18) may be eliminated because the general environment for launch and reentry will not have significant effect on ability of the crew to perform control tasks.

(2) Zero-g training simulation performed by Keplerian flights of a KC-135 type aircraft (Item 19) may be eliminated in favor of Neutral Buoyance Training facility. Relatively simple EVA-IVA tasks expected to be accomplished by orbiter crew may be performed for training purposes in existing NBT facilities at a cost savings over zero-g facility.

(3) Zero-g cargo handler training (Item 20) facility may also be eliminated in deference to NBT facility which will provide adequate training.

(4) Full-scale docking procedures training (Item 23) would be eliminated from Plan II to save the cost of activating a single facility for one particular training mission that could be done concurrently in the mission procedures training simulator (Item 14) by using generated out the window displays rather than actual size mockups of docking targets.

(5) In-flight training is considered too costly for the added fidelity of simulation to be gained over conventional motion-base simulators. Justification for a variable stability aircraft to achieve deep technical penetration in Plan I is based on using the aircraft to support development of subsonic GN&C systems in addition to training. This plan provides a broader utilization of the facility and justifies the initial cost of aircraft conversion to orbiter configuration. Items 25 and 26 would be eliminated in the low cost, adequate penetration Plan II in deference to fixed base engineering and moving base training simulators.

Hardware verification simulations (Items 29-35) conducted as a part of verification testing using a systems integration laboratory facility are of sufficient importance to vehicle development to warrant parallel contractor and NASA activities as shown in Plan I. This plan gives deep technical penetration at a high facility cost (see description of facility in Appendix E). Plan II

calls for cost reduction through limiting verification simulation activities (and facility requirements) to contractor only. Since this simulation activity is tied closely to hardware development, it is primarily a contractor responsibility whether Plan I or II is implemented.

The remaining all-digital computer simulations (Items 36-69) are basically design simulations. As such, they are of prime interest to the contractor. In most cases, high technical penetration is indicated in Plan I by combined contractor and NASA activities. The low cost, adequate penetration approach of Plan II indicates simulations to be done by contractor only. Exceptions which should be noted are listed as follows:

(1) Simulations with objectives primarily for support of vehicle subsystems design are shown in Plan I as being responsibility of the contractor only. Items 44, 54-63 are included in this category. Most of these simulations are considered essential and are included in both plans except as noted in Appendix B.

(2) Two simulations involving structural/propulsion stability analysis (Items 46 and 48) in Plan II would be done by NASA because of experience factor, computing facility requirements, and necessary integration activity between airframe and engine contractors.

(3) Simulations oriented towards similar problems were combined in Plan II. Combined simulations are noted in Appendix B.

4.2.3 <u>Summary of Alternate Integrated Plans</u> - A summary of the alternate Booster and Orbiter simulation plans showing division of responsibility between NASA centers and contractors is presented in Figures 4.2.3-1 and 4.2.3-2. The data taken from Appendix B, indicates the number of simulation tasks to be performed and facilities required by each NASA center and contractor. Comparative levels of activity and facility requirements in Plan I clearly indicate the use of multiple simulations on the part of each center/contractor team as a means to affect maximum technical penetration.

The matrix is set up to show the number of simulation tasks, in terms of design support, hardware verification, procedures development, and training categories. It becomes obvious from the alignment of simulations within these categories that Plan II assigns simulation tasks by characteristic NASA center/ contractor roles in vehicle development. The contractor assumes basic responsibility

SUMMARY OF BOOSTER ALTERNATE SIMULATION PLANS

	PLAN I		PLAN II	
SRD'S	62		52	
	NASA	CONTRACTOR	NASA	CONTRACTOR
SIMULATION TASKS				
o Design Support	33	45	4	34
o Hardware Verification	8	9		9
o Procedures Development	2		2	
o Training	5		3	
Total Center/Contractor Simulation Tasks	48	54	9	43
Generic Facilities	11		10	
Total Center/Contractor Facility Requirements	10	6	6	5

FIGURE 4.2.3-2

SUMMARY OF ORBITER ALTERNATE SIMULATION PLANS

	PLAN I		PLAN II	
SRD'S	69		54	
	NASA	CONTRACTOR	NASA	CONTRACTOR
SIMULATION TASKS				
o Design Support	30	42	6	31
o Hardware Verification	10	10		9
o Procedures Development	4		3	
o Training	9		5	
Total Center/Contractor Simulation Plans	53	52	14	40
Generic Facilities	16		10	
Total Center/Contractor Facility Requirements	13	6	7	5

FIGURE 4.2.3-1

for the majority of design support and hardware verification simulation tasks under NASA center cognizance. Each NASA center is responsible for simulations to support procedures development, mission planning and crew training. Plan II eliminates multiple simulations and divides the total simulation task between center and contractor.

Estimates of facility non-recurring and operating costs were made to provide an indicated magnitude of cost reduction for plan II over plan I. A 36% cost reduction in Booster center/contractor facilities was derived from comparative cost estimates. This figure was based on combined center/contractor costs of $77.4 million for plan I and $49.3 million for plan II. A 38% cost reduction in Orbiter center/contractor facilities was derived from comparative cost estimates. This figure was based on combined center/contractor costs of $82.5 million for plan I and $50.7 million for plan II. These estimates, a portion of total simulation costs which are included in Phase B vehicle development cost estimates, represent direct facility costs derived by using criteria discussed in Section 3.2.

5.0 CONCLUSIONS

This simulation planning study has identified a large number of activities and costly resouces (facilities) required to support Space Shuttle vehicle development. Efficient utilization of these activities and resources may be achieved at a cost savings through effective planning and scheduling. Technical descriptions of individual simulation activities were generated to aid in establishing the advisability of the simulation and level of simulation activity required to adequately support system engineering and integration.

Two different plans have been provided to allow evaluation of alternatives in terms of technical penetration and cost. Plan I represents high technical penetration attained primarily through joint efforts of the NASA center/contractor team in executing multiple simulations with resulting overlap in technical efforts. Plan II will provide adequate technical penetration by eliminating multiple simulations, eliminating simulation tasks that do not prove to be cost effective, and aligning simulation responsibilities to characteristic center/contractor roles.

The final simulation plan selected for implementation in Booster and Orbiter vehicle development may be used:

(1) As an overview of vehicle development from the standpoint of simulation support.

(2) As an interactive device for scheduling simulation activities and reacting to contingencies.

(3) As a general specification for simulation facilities and timetable for their activation and use.

6.0 RECOMMENDATIONS

(1) A baseline plan should be derived from the alternatives presented. This plan should be complete by issuance of authority to proceed on Phase C. Early decision on content of the baseline simulation plan is necessary because simulation activities are scheduled immediately after ATP and early buildup of certain facilities is required.

(2) Additional activity should be directed toward developing a simulation plan based on contingencies of a phased approach to Space Shuttle development. Addition of non-reusable Booster, or phased development of reusable Booster will have an extensive effect on the baseline simulation plan.

(3) Maturation of individual SRD's should be continued by providing additional technical detail, refining schedules, providing cost data and updating general content. Mature SRD's provide better visibility of the simulation activity and are more useful aids for planning and decision making. Information relative to vehicle development is continually being generated and should be incorporated in the SRD's.

(4) A trade study should be performed to evaluate construction of new simulation facilities versus modification and use of existing facilities at NASA and industry sites.

(5) An interactive computer program (TLGEN or equivalent) for the purpose of applying and maintaining an automated scheduling activity should be used by NASA or contractor project offices to plan and schedule facility usage, maintain current status and provide for alternate solutions to scheduling problems that may occur during development.

APPENDIX A

SIMULATION REQUIREMENTS DESCRIPTIONS

SRD 1.1.1.1.1

MAN-IN-THE-LOOP GUIDANCE, NAVIGATION AND CONTROL SYSTEM DESIGN VERIFICATION SIMULATIONS - BOOSTER

OBJECTIVE: Objectives of these simulations are to evaluate the guidance, navigation and control systems design from the flight crew's point of view and determine operational procedures and performance. The outputs of these simulation will be

- o Evaluation of acceptability of manual techniques
- o Evaluation of cockpit GN&C displays and controls
- o Definition of onboard software operational requirements
- o Man-in-the-loop impact on ΔV or fuel requirements to perform a task

JUSTIFICATION: These simulations enable evaluation of the subsystems conceptual designs by qualified personnel at a time when the design can be changed or influenced with little cost impact.

DESCRIPTION: These man-in-the-loop simulations are similar to the digital computer simulations discussed in Flight Mechanics SRD's 4.1.1.1, 4.1.1.2, 4.1.1.3 and 4.1.1.4. The obvious addition is the implementation of manual modes of operation and a crew station. Only those crew station displays and controls necessary for the particular simulation shall be active.

New math models will be developed to drive any required out-the-window displays e.g. earth horizon, terrain features and landing field presentations.

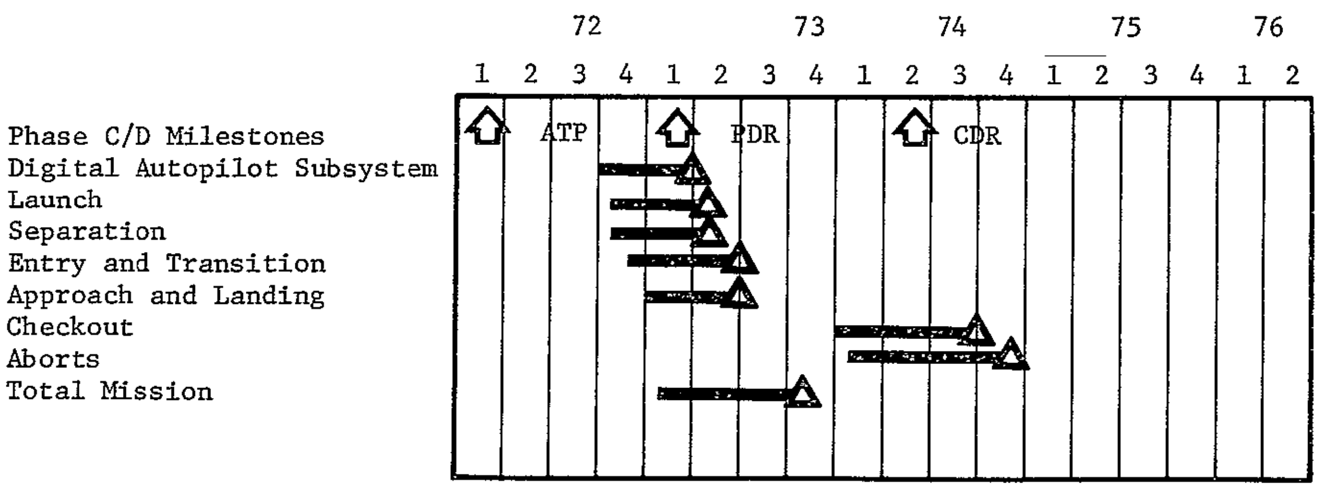
Input data for these man-in-the-loop simulations will be similar to their all digital counterparts. In many cases it is expected that manual mode man-in-the-loop runs will attempt to duplicate automatic mode digital computer simulations for evaluation of man's impact on system operation.

This Simulation Requirements Description covers all those booster GN&C conceptual simulation studies performed to evaluate the handling techniques and cockpit displays and controls design for manual modes of operation. Consequently, the simulations shall be mission phase oriented as follows:

Vehicle	Simulation
Mated Booster/Orbiter (Simulations performed in each crew station - not simultaneously)	o Checkout o Liftoff o Launch o Separation o Aborts
Booster	o Digital Autopilot System (All modes of operation) o Launch o Entry and transition o Terminal approach and landing o Total Mission o Aborts

FACILITIES: These man-in-the-loop simulation require a hybrid computing facility and a simulated crew station with appropriate out-the-window displays and active instrumentation and controls. The crew station need only be equipped as necessary for the particular simulation being considered. Details of the crew station facility requirements are presented in Appendix D.

SCHEDULE: These simulations shall be performed sufficiently early to impact crew station instrumentation design and onboard software development.



NOTE: Only facility run times are shown.

SRD 1.1.1.1.2

MAN-IN-THE-LOOP PROCEDURES DEVELOPMENT AND FUNCTIONAL SIMULATION - BOOSTER

OBJECTIVE: The simulations covered by this description will be designed to support the development of the pilot's flight procedures for Booster aerodynamic flight regime. Outputs from these simulations shall include:

- o Development of and evaluation of aerodynamic flight procedures
- o Evaluation of atmospheric flying qualities and performance characteristics
- o Evaluation of flight software
- o Evaluation of GN&C displays and controls
- o Evaluation of software flexibility for various missions

JUSTIFICATION: These simulations enable users (crew members) to evaluate and participate in the design and development GN&C flight software and hardware. Use of man-in-the-loop simulation techniques in design of complex GN&C systems has proven its cost effectiveness on past programs.

DESCRIPTION: The man-in-the-loop simulations covered by this SRD represent the highest fidelity simulations from the standpoint of crew station environment normally considered cost effective during the design and development phase. The onboard software is simulated with respect to timing, equation format and sequence of execution. The simulated onboard software for this simulation shall be obtained by modifying the programs described in Functional Software Simulations (SRD 7.1.1.1). All vehicle hardware systems providing data to the onboard computer.(e.g., IMU functional hardware) is simulated along with the capability to input probable system errors. The environment for the simulations covered by this SRD is described in Appendix B. Additional math models of hardware systems for these simulations and the appropriate mission phases are shown in the following table:

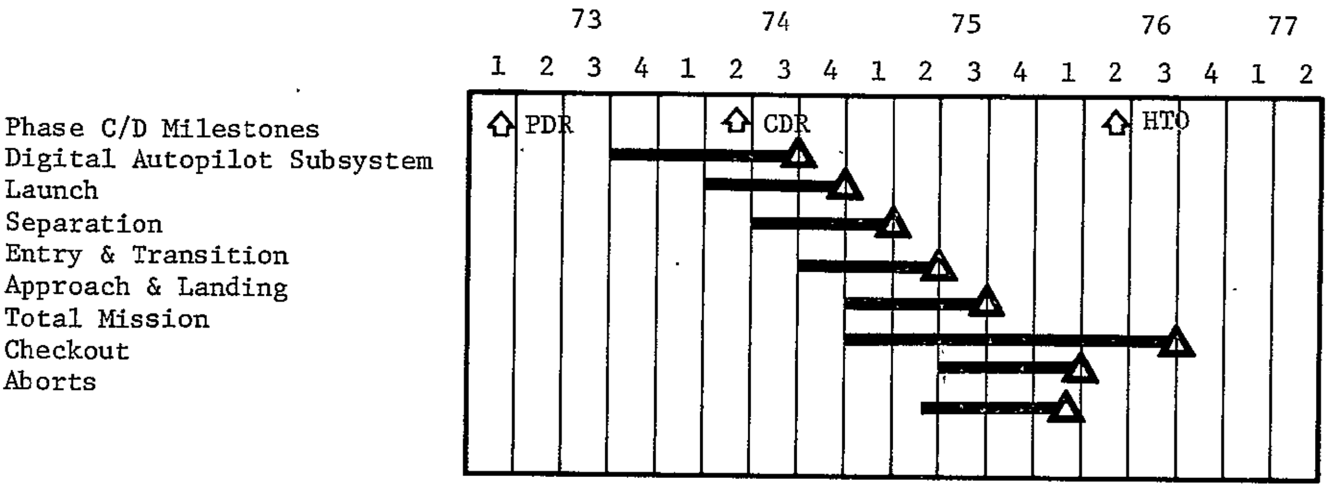
HARDWARE SYSTEM TO BE MODELED	ASCENT	ENTRY	TRANSITION	SUBSONIC
Inertial Meas. Unit	X	X	X	X
Rate Gyros	X	X	X	X
Attitude Control Prop. System	X	X	X	
Thrust Vector Control System	X			
Air Data Set				X
Radar Altimeter				X
DME, VOR, ILS				X
Body Mounted Accelerometers	X			X

Input data for these simulations will come from the digital computer Flight Dynamics simulations, the digital computer Flight Mechanics simulations and the man-in-the-loop system design verification simulation. The real-time simulations covered by this description are listed as follows:

Vehicle	Simulation
Mated Booster/Orbiter	o Launch (Liftoff thru separation)
	o Aborts
	o Checkout
Booster	o Digital Autopilot System
	o Launch
	o Entry & Transition
	o Terminal Approach & Landing
	o Total Mission
	o Ferry Mission
	o Checkout
	o Aborts

FACILITY: A hybrid computing facility and a fully active engineering crew station (instrumentation, displays and flight controls) are required for these simulations. Provisions for out-the-window displays shall include earth horizon, star field, terrain features and landing field representations. Details of the facility requirements are presented in Appendix D.

SCHEDULE: Simulations shall be performed sufficiently early to provide inputs for development of the flight software, GN&C instrumentation, displays, flight controls hardware designs and aerodynamic configuration.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1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2
PDR
CDR
HTO
Phase C/D Milestones
Digital Autopilot Subsystem
Launch
Separation
Entry & Transition
Approach & Landing
Total Mission
Checkout
Aborts

SRD 1.1.1.1.3

BOOSTER MANNED BACKUP BOOST CONTROL

OBJECTIVE: The objective of this simulation is to determine the feasibility of manned backup control for stabilizing the space shuttle during boost to increase the probability of overall mission success. Outputs should include:

- Evaluation of guidance accuracy
- Analysis of induced structural loads
- Analysis of body bending movements at critical locations
- Evaluation of backup control under failure mode conditions

JUSTIFICATION: The unique configuration of the space shuttle makes it impossible to directly relate its control characteristics to other vehicles. For this reason it is necessary to perform a simulation using the specific characteristics of the space shuttle to derive backup control stabilization techniques which should increase the mission success probability.

DESCRIPTION: This simulation should utilize a fixed-base cockpit along with the mathematical computer simulation which should include five rigid body degrees of motion, two modes of elastic body motions and fuel-sloshing dynamics. Guidance should consist of a pitch attitude open-loop time program. In addition to stabilizing attitude and reducing structural loads due to the wind, the pilot could be required to roll the vehicle to the proper downrange heading after takeoff. Disturbance inputs should include:

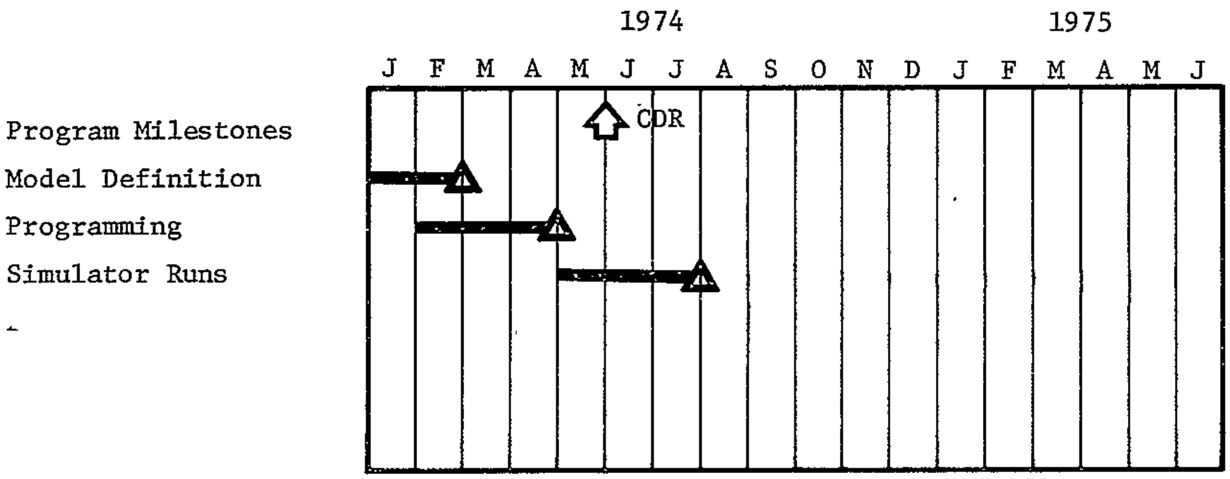
- Steady state wind
- Wind shear
- Gusts
- Turbulence
- Propellant-sloshing dynamics
- Engine out conditions

Pilot control capability can be measured through monitoring his ability to:

- o Control distance and velocity dispersions normal to the nominal trajectory
- o Minimizing the rigid-body bending moment
- o Stabilizing the roll attitude

FACILITY: A general purpose digital computer in combination with a fixed base crew station can be utilized to run this simulation. Details of the facility requirements are detailed in Appendix D.

SCHEDULE: This simulation is run concurently with abort analysis man-in-the-loop simulations and prior to Environmental Ascent/Reentry Analysis.



SRD 1.1.1.2.1

MAN-IN-THE-LOOP GUIDANCE, NAVIGATION AND CONTROL SYSTEM DESIGN VERIFICATION SIMULATIONS - ORBITER

OBJECTIVE: Objectives of these simulations are to evaluate the guidance, navigation and control systems design from the flight crew's point of view and determine operational procedures and performance. The outputs of these simulations will be:

- Evaluation of acceptability of manual techniques
- Evaluation of cockpit GN&C displays and controls
- Definition of onboard software operational requirements
- Man-in-the-loop impact on ΔV or fuel requirements to perform a task

JUSTIFICATION: These simulations enable evaluation of the subsystems conceptual designs by qualified personnel at a time when the design can be changed or influenced with little cost impact.

DESCRIPTION: These man-in-the-loop simulations are similar to the digital computer simulations discussed in Flight Mechanics SRD's 4.1.2.1, 4.1.2.2, 4.1.2.3 and 4.1.2.4. The obvious addition is the implementation of manual modes of operation and a crew station. Only those crew station displays and controls necessary for the particular simulation shall be active.

New math models will be developed to drive any required out-the-window displays, e.g. earth horizon, star field docking target, terrain features and landing field presentations.

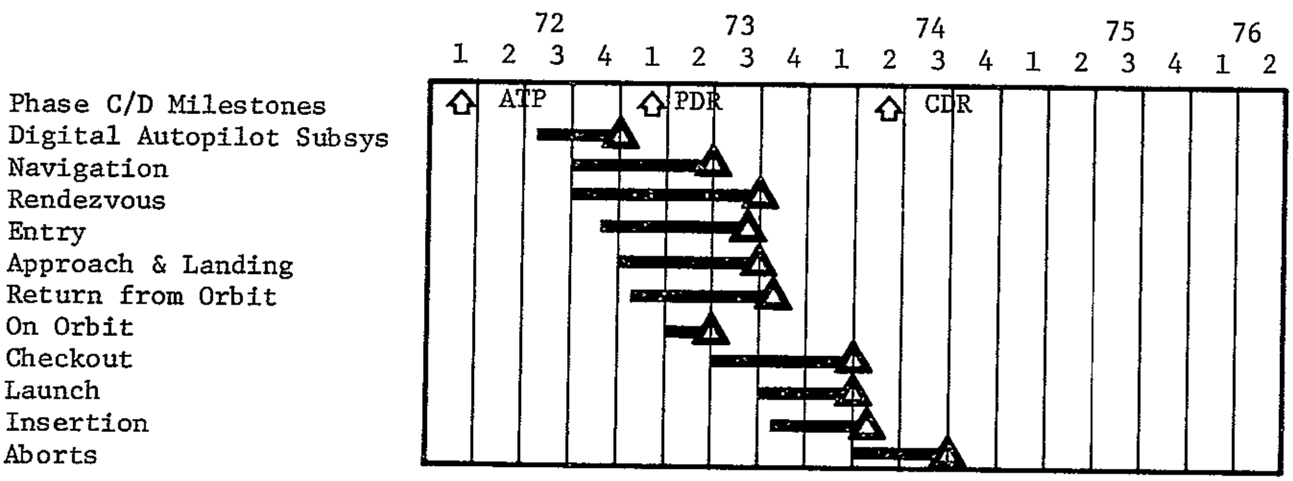
Input data for these man-in-the-loop simulations will be similar to their all digital counterparts. In many cases it is expected that manual mode man-in-the-loop runs will attempt to duplicate automatic mode digital computer simulations for evaluation of man's impact on system operation.

This Simulation Requirements Description covers all those GN&C conceptual simulation studies performed to evaluate the handling techniques and cockpit displays and controls design for manual modes of operation. Consequently, the simulations shall be mission phase oriented as follows:

- o Digital Autopilot System (all modes of operation)
- o Navigation (Platform Alignment, Scanner, Tracker, VHF and Hybrid Navigation)
- o Rendezvous
- o On orbit (station keeping, docking, deorbit)
- o Entry & transition
- o Approach & Landing
- o Ascent/Separation thru insertion
- o Aborts
- o Checkout

FACILITIES: These man-in-the-loop simulations require a hybrid computing facility and a simulated crew station with appropriate out-the-window displays and active instrumentation and controls. The crew station need only be equipped as necessary for the particular simulation being considered.

SCHEDULE: These simulations shall be performed sufficiently early to impact crew station instrumentation design and onboard software development.



NOTE: Only run times shown

SRD 1.1.1.2.2
MAN-IN-THE-LOOP PROCEDURES DEVELOPMENT AND FUNCTIONAL SIMULATION - ORBITER

OBJECTIVE: The simulations covered by this description will be designed to enable the development of the pilot's flight procedures for Orbiter aerodynamic flight and orbital phases of a mission. Outputs will be in the form of:

- o Development and evaluation of flight procedures
- o Evaluation of atmospheric flying qualities and performance characteristics
- o Evaluation of man-in-the-loop performance for orbital functions
- o Evaluation of onboard software
- o Evaluation of displays and controls
- o Evaluation of flexibility of software for various missions

JUSTIFICATION: These simulations enable (crew members) to evaluate and participate in the design and development GN&C flight software and hardware. Use of man-in-the-loop simulation techniques in design of complex GN&C systems has proven its cost effectiveness on past programs.

DESCRIPTION: The man-in-the-loop simulations covered by this SRD represent the highest fidelity simulations from the standpoint of crew station environment during the design and development phase. The onboard software is simulated with respect to timing, equation format and sequence of execution. The simulated onboard software for this simulation shall be obtained by modifying the programs described in Functional Software Simulations (SRD 7.1.2.1). All vehicle hardware systems providing data to the onboard computer (e.g., IMU functional hardware) is simulated along with the capability to input probable system errors. The environment for the simulations covered by this SRD is described in Appendix B. Additional math models of hardware systems for these simulations and the appropriate mission phases are shown in the following table:

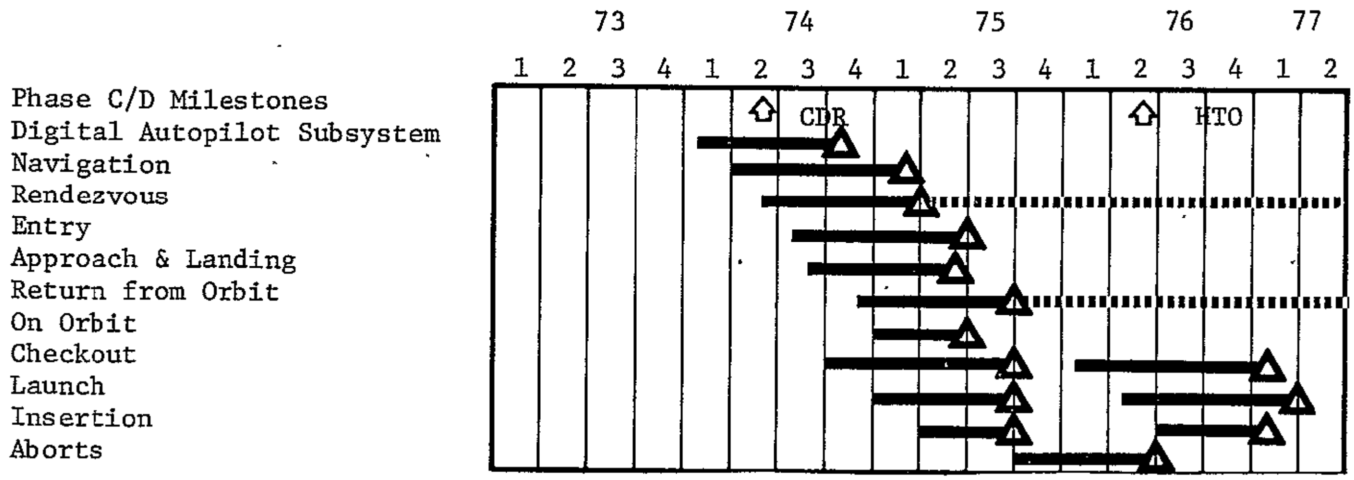
HARDWARE SYSTEM TO BE MODELED	ASCENT	ENTRY	TRANSITION	SUBSONIC	ON ORBIT
Inertial Meas. Unit	X	X	X	X	X
Rate Gyros	X	X	X	X	
Attitude Control Prop. System	X	X	X		X
Orbital Maneuvering System					X
Thrust Vector Control System	X				
Air Data Set				X	
Radar Altimeter				X	
DME, VOR, ILS				X	
Body Mounted Accelerometers	X			X	

Input data for these simulations will come from the digital computer Flight Dynamics simulations, the all digital computer Flight Mechanics simulations and the man-in-the-loop system design verification simulation. The real-time simulations covered by this description are listed as follows:

- o Digital Autopilot System
- o Ascent/Separation thru insertion
- o On-Orbit (Station keeping, docking, deorbit)
- o Rendezvous
- o Entry & transition
- o Approach & landing
- o Return from orbit
- o Navigation models
- o Checkout
- o Aborts
- o Ferry Mission

FACILITY: A hybrid computing facility and a fully acrive engineering crew station (instrumentation, displays and flight controls) are required for these simulations. Provisions for out-the-window displays shall include earth horizon, star field, terrain features and landing field representations. Detailed description of the crew station is presented in Appendix D.

SCHEDULE: Simulations shall be performed sufficiently early to provide inputs for development of the flight software and GN&C instrumentation, displays and flight controls hardware designs and aerodynamic configuration.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1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2
Phase C/D Milestones
Digital Autopilot Subsystem
Navigation
Rendezvous
Entry
Approach & Landing
Return from Orbit
On Orbit
Checkout
Launch
Insertion
Aborts
CDR
HTO

SRD 1.1.1.2.3

ORBITER DOCKING PROCEDURES DESIGN ANALYSIS

OBJECTIVE: The purpose of this simulation is to evaluate control tasks and develop techniques for performing man-in-the-loop docking maneuvers. Outputs of this task shall include:

- o Evaluation of reaction control system design related to the docking task
- o Evaluation and choice of rendezvous and docking sensors
- o Evaluation of docking aids
- o Development of unique shuttle docking procedures involving a variety of potential targets
- o Evaluation of manual versus automatic docking methods

JUSTIFICATION: This simulation enables design engineering personnel and flight crews to assess the adequacy of vehicle design from the standpoint of control requirements for docking maneuvers. Necessity to place a crew member in a position other than the normal flight position for docking activities creates a new set of operational requirements. Design of a special station, restraint system, and display and control configuration for performance of the docking task will require utilization of a new set of visual cues, due to the operator's position and distance from the extended payload deployed from the cargo area. Simulation represents the best method of developing these docking techniques by placing the operator in the exact visual environment encountered in actual docking maneuvers.

DESCRIPTION: A fixed base docking control station with associated controls and displays, payload docking window, and out-the-window displays shall comprise the crew station portion of the simulation facility. A variety of target presentations shall be used to provide out-the-window displays. The target information shall be displayed on closed circuit television, projected as a virtual image and viewed through the payload docking window. The field of view is directed out the payload docking window with line of sight essentially parallel to the longitudinal axis of the extended payload. The target presentations shall be generated from scale models and computer graphics. Docking control station shall contain functioning mockups of translation/rotation controllers, and associated attitude and status displays. Control station geometry shall be representative of actual vehicle including seat restraints, panels, and bulkheads.

Simulation computer shall contain six-degree-of-freedom vehicle equations of motion, reaction controls system mechanization, sensor error effects, mode control

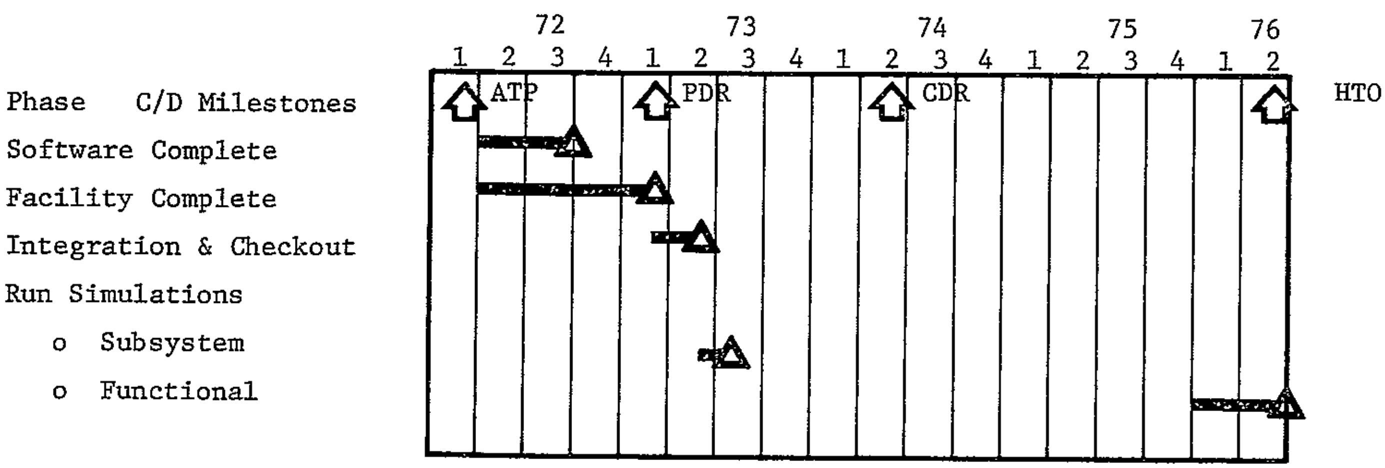
logic for manual or automatic docking maneuvers, and transformation equations for driving target presentations. The program shall be executed in real-time.

Typical simulation runs shall begin at a distance of 300 meters and continue to contact with the target vehicle.

Subsystem simulation runs shall be conducted early in vehicle development for evaluation of system design and verification of controls and displays hardware. Simple computer generated graphic presentations of target vehicles may be used at this point. Functional simulation to evaluate and approve final design and develop preliminary procedures shall be run later in the program. Out-the-window displays generated from target vehicle models and closed circuit television shall be used for added realism.

FACILITY: Facility requirements include a docking control station mockup, and out-the-window visual display of target presentations interfaced with a simulation computer providing solutions to vehicle equations of motion and target transformations.

SCHEDULE: Subsystem simulation shall be concurrently completed by August 1973. Functional simulations shall be run during 1976 to evaluate flight software and develop docking procedures.



SRD 1.1.2.1.1

BOOSTER CREW/COMPUTER INTERFACE DESIGN EVALUATION

OBJECTIVE: This simulation shall function as an aid in design and development of the booster crew station video display subsystem and display data formats. Output of this simulation task includes:

- o Verification of video display subsystem hardware design
- o Development of display calling procedures
- o Development of display formats
- o Development of symbology
- o Development of subsystem software

JUSTIFICATION: This Space Shuttle application represents the first large scale use of an interactive graphics crew/computer interface for vehicle subsystems management. The crew/computer interface subsystem development is best accomplished through an iterative process, involving computer simulation techniques. This process allows evaluation of a large number of candidate display formats and procedures in a short time span. Adequacy of design is dependent on man's ability to use the crew/computer interface in the actual environment, therefore man-in-the-loop simulation is the best verification technique.

DESCRIPTION: The task of developing crew/computer interface hardware and video display presentations will be accomplished with the aid of functional man-in-the-loop simulation techniques in two phases:

- o Phase I-Develop static data formats for video display by utilizing general purpose digital computer with interactive graphics terminal.
- o Phase II-Evaluate dynamic display formats in simulated mission operations using part-task mission simulation.

Phase I - Inputs to this phase are mission profiles and event timelines derived from engineering analyses and flight dynamics simulations for various mission phases. A functional simulation of the booster vehicle video display subsystem shall be mechanized on a general purpose computer with interactive graphics display capability. Based on mission profiles and event timelines the necessary software will be designed and implemented within the general-purpose computer to display various format designs on the graphics terminal. In addition to individual formats, the software necessary for the display and control data base and executive subprograms for calling procedures will be developed. Engineering and human factors evaluations of the original format shall be made, and operational subsystem designs iterated until acceptable configurations are achieved.

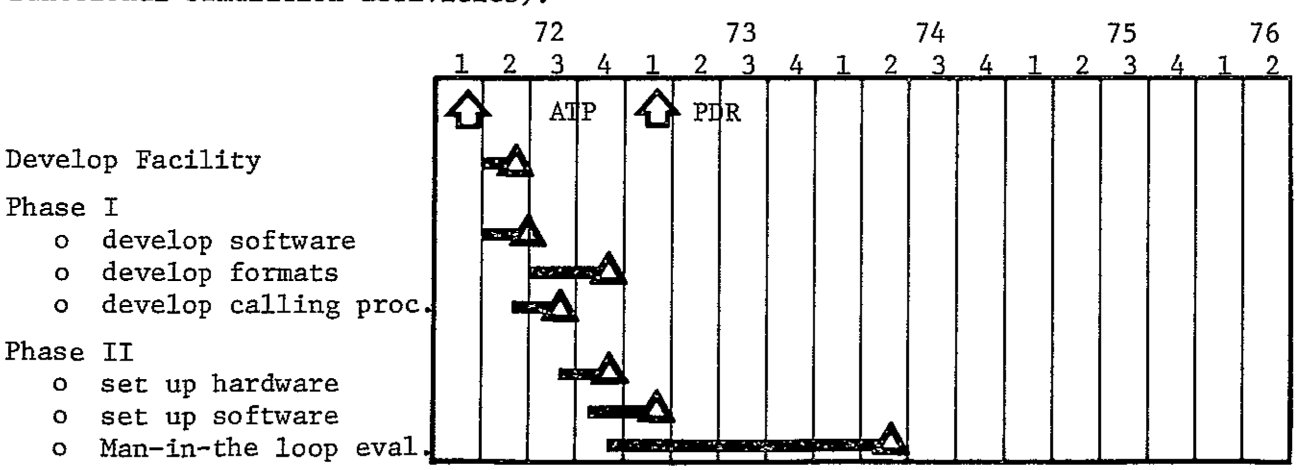
Phase II - Inputs to this phase consist of display formats and the operating software system developed in Phase I. Flight crew evaluation of display data formats will be conducted by performing man-in-the-loop real-time part-task simulations of GN&C and subsystems management tasks for a given mission phase using the series of display formats developed for that phase. A pilot rating system will be formulated to obtain feedback for the iterative process of final display system and format design.

Hardware requirements for Phase II include the engineering crew station simulator with dedicated display and control equipment interfaced to the computer mechanization of vehicle dynamics for all mission phases.

Additional display hardware required for this simulation task consists of multiple cathode-ray tubes and control keyboards mounted in their proper locations on the crew station instrument panel.

FACILITY: Two specific facilities are required for this task; a general purpose digital computer with interactive graphic display capability for Phase I, and an engineering crew station simulator facility for Phase II. The crew station simulator, described in detail in Appendix D, also requires multiple video display tubes, keyboards and associated computer interfaces. Additional special purpose hardware equipment may be required to generate fixed display formats depending on how this problem is handled in the vehicle display and control subsystem design (i.e., through hardware or software implementation).

SCHEDULE: Phase I will begin with the start of Shuttle program phase C. Phase II may begin in parallel with Phase I and will be run on a time shared basis with other simulation tasks required for GN&C and subsystem management development (e.g., reentry display and control formats shall be evaluated during reentry GN&C functional simulation activities).



SRD 1.1.2.2.1

ORBITER CREW/COMPUTER INTERFACE DESIGN EVALUATION

OBJECTIVE: This simulation shall function as an aid in design and development of the orbiter crew station video display subsystem and display data formats. Output of this simulation task includes:

- o Verification of video display subsystem hardware design
- o Development of display calling procedures
- o Development of display formats
- o Development of symbology
- o Development of subsystem software

JUSTIFICATION: This Space Shuttle application represents the first large scale use of an interactive graphics crew/computer interface for vehicle subsystems management. The crew/computer interface subsystem development is best accomplished through an iterative process, involving computer simulation techniques. This process allows evaluation of a large number of candidate display formats and procedures in a short time span. Adequacy of design is dependent on man's ability to use the crew/computer interface in the actual environment, therefore man-in-the-loop simulation is the best verification technique.

DESCRIPTION: The task of developing crew/computer interface hardware and video display presentations will be accomplished with the aid of functional man-in-the-loop simulation techniques in two phases:

- o Phase I-Develop static data formats for video display by utilizing general purpose digital computer with interactive graphics terminal.
- o Phase II-Evaluate dynamic display formats in simulated mission operations using part-task mission simulation.

Phase I - Inputs to this phase are mission profiles and event timelines derived from engineering analyses and flight dynamics simulations for various mission phases. A functional simulation of the booster vehicle video display subsystem shall be mechanized on a general purpose computer with interactive graphics display capability. Based on mission profiles and event timelines the necessary software will be designed and implemented within the general-purpose computer to display various format designs on the graphics terminal. In addition to individual formats, the software necessary for the display and control data base and executing subprograms for calling procedures will be developed. Engineering and human

factors evaluations of the original format shall be made, and operational subsystem designs iterated until acceptable configurations are achieved.

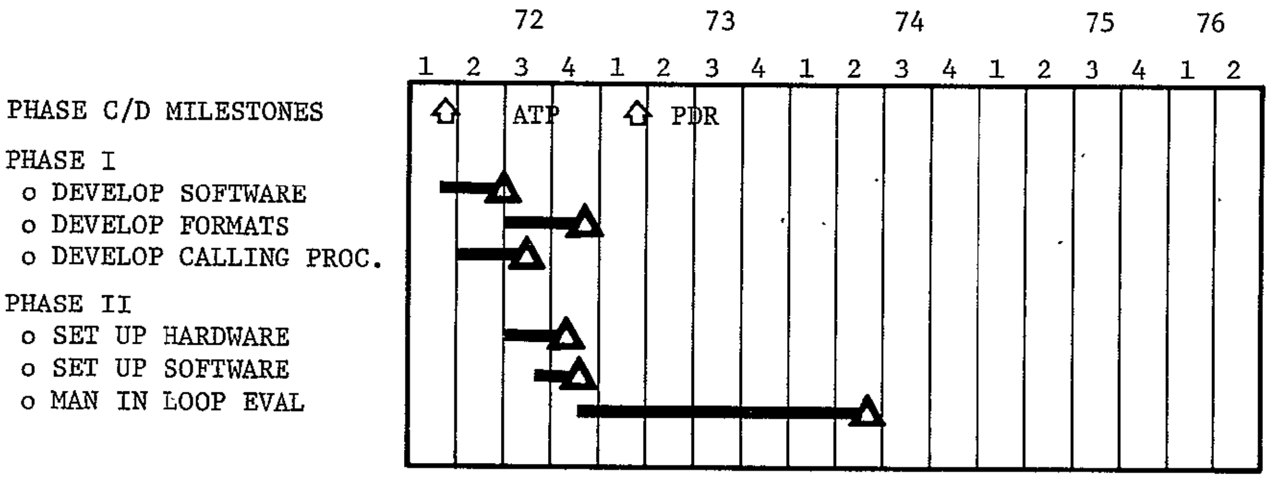
Phase II - Inputs to this phase consist of display formats and the operating software system developed in Phase I. Flight crew evaluation of display data formats will be conducted by performing man-in-the-loop real-time part-task simulations of GN&C and subsystems management tasks for a given mission phase using the series of display formats developed for that phase. A pilot rating system will be formulated to obtain feedback for the iterative process of final display system and format design.

Hardware requirements for Phase II include the engineering high fidelity crew station mockup with dedicated display and control equipment interfaced to the computer mechanization of vehicle dynamics for all mission phases.

Additional display hardware required for this simulation task consists of multiple cathode-ray tubes and control keyboards mounted in their proper locations on the crew station instrument panel.

FACILITY: Two specific facilities are required for this task; a general purpose digital computer with interactive graphic display capability for Phase I, and an engineering crew station simulator facility for Phase II. The crew station simulator, described in detail in Appendix D, also requires multiple video display tubes, keyboards and associated computer interfaces. Additional special purpose hardware equipment may be required to generate fixed display formats depending on how this problem is handled in the vehicle display and control subsystem design (i.e., through hardware or software implementation).

SCHEDULE: Phase I will begin with the start of Shuttle program phase C. Phase II may begin in parallel with Phase I and will be run on a time shared basis with other simulation tasks required for GN&C and subsystem management development (e.g., reentry display and control formats shall be evaluated during reentry GN&C functional simulation activities).


72
73
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1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2
PHASE C/D MILESTONES
ATP
PDR
PHASE I
o DEVELOP SOFTWARE
o DEVELOP FORMATS
o DEVELOP CALLING PROC.
PHASE II
o SET UP HARDWARE
o SET UP SOFTWARE
o MAN IN LOOP EVAL

SRD 1.1.3.1.1

BOOSTER CREW STATION CONTROLS & DISPLAYS DESIGN VERIFICATION

OBJECTIVE: The purpose of this task is to verify subsystem design and hardware/software interface for nonavionic controls and displays that are driven by data bus information. Vehicle subsystems with displays and controls in this category include:

- o Electrical Power Subsystem
- o Hydraulic Power Subsystem
- o Environmental Control and Lift Support Subsystem
- o Propulsion and Propellant Management Subsystem
- o Auxiliary Propulsion Unit

Outputs of this simulation include:

- o Functional design acceptability of nonavionics controls and displays (part I)
- o Verify capability to manage subsystems functions (parts I and II)
- o Verification of displays and controls hardware/software interface (part II)

JUSTIFICATION: Part I represents the first evaluation of nonavionics displays and controls for subsystems management in an operational environment. Functional acceptability of displays and controls interfacing with man-in-the-loop must be evaluated early to insure required design changes will minimize impact on program cost. A full simulation of actual flight operation provides deep technical penetration of the displays and controls design. Verification of hardware/software interface is necessary to insure compatibility of the displays and controls with the data management system in terms of scaling, data flow, mode switching, and general operating procedures.

DESCRIPTION: These simulations shall be performed in two parts. Part I is a verification of dedicated subsystems displays and controls design through use of real-time part-task simulation techniques. Part II is hardware/software verification of onboard subsystems controls and displays using actual flight software.

Part I - Verification of displays and controls design using prototype hardware is accomplished early in subsystem development so that any necessary hardware changes may be implemented at reasonable cost. Prototype dedicated subsystems displays that are driven by data bus information shall be installed in the engineering crew station simulator. Programs representing subsystem management

logic shall be written and mechanized in the simulation computer. These subroutines shall be cued to events in GN&C simulation programs for various mission phases. In this manner, dedicated subsystem displays may be evaluated in a dynamic crew station environment. Hardware prototypes of the following subsystems displays and controls shall be installed in the crew station mockup.

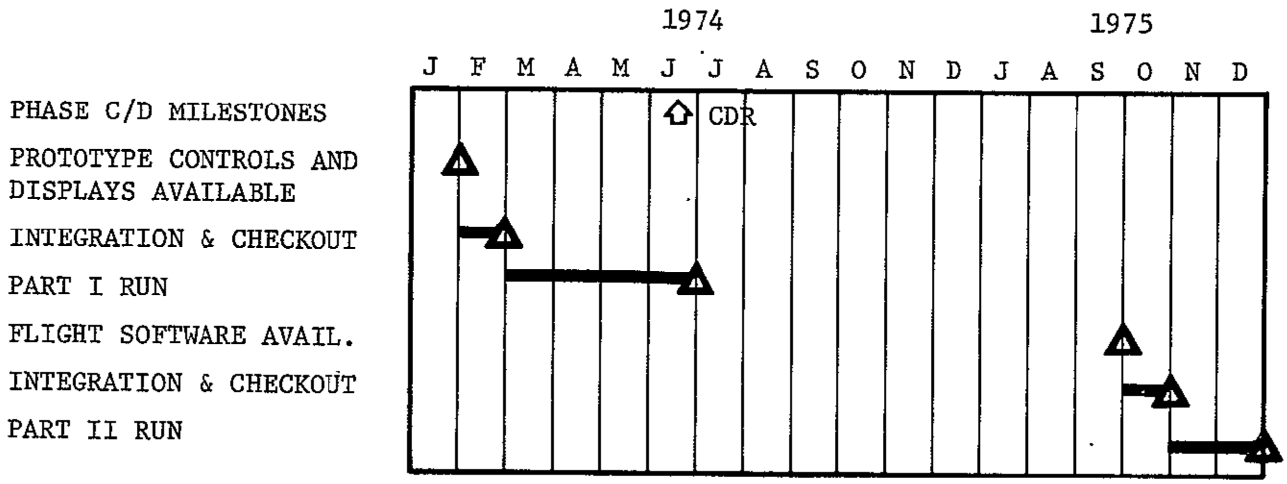
- o Fuel transfer and vent tank
- o ECLS
- o Electrical Displays
- o Fuel Cell & Power Distr.
- o Main engines
- o Propulsion (Air breathing)
- o APU and Hydraulic System Control
- o Circuit Protection

These instruments and controls shall be interfaced with the simulation computer through standard bi-level and analog/digital converter interface equipment.

Part II - As much actual subsystems hardware as practical shall be used in performing the controls and displays hardware/software verification. A systems-integration laboratory facility shall be used, which will include redundant operational avionics and hydraulics systems hardware, complete crew station simulator, and simulation computer. The simulation computer shall enable closed-loop performance of vehicle subsystems through a real-time simulated mission by providing vehicle models, environment models, G&N sensor models, and subsystem simulations (e.g., propulsion, ECLS, communications). The subsystems controls and displays hardware/software interface be evaluated by exercising controls in typical subsystem management routines.

FACILITY: Facility requirements range from the engineering crew station simulator and simulation computer with simulated displays and controls interface in part I, to incorporation of complete systems integration laboratory hardware facility in part II. Descriptions of crew station simulator and systems integration laboratory are presented in Appendices D and E, respectively.

SCHEDULE: Part I is accomplished upon availability of prototype displays and controls (Feb. 1974). Part II is accomplished during first part of hardware/software validation (SRD 6.1.1) prior to horizontal flight.


1974
1975
J F M A M J J A S O N D J A S O N D
PHASE C/D MILESTONES
CDR
PROTOTYPE CONTROLS AND DISPLAYS AVAILABLE
INTEGRATION & CHECKOUT
PART I RUN
FLIGHT SOFTWARE AVAIL.
INTEGRATION & CHECKOUT
PART II RUN

SRD 1.1.3.1.2

BOOSTER VISUAL AND AUDITORY WARNING SYSTEM SIMULATION

OBJECTIVE: The objective of this task is to use simulation techniques to aid in development of visual and auditory warning systems in the booster vehicle. Outputs of the simulation shall include:

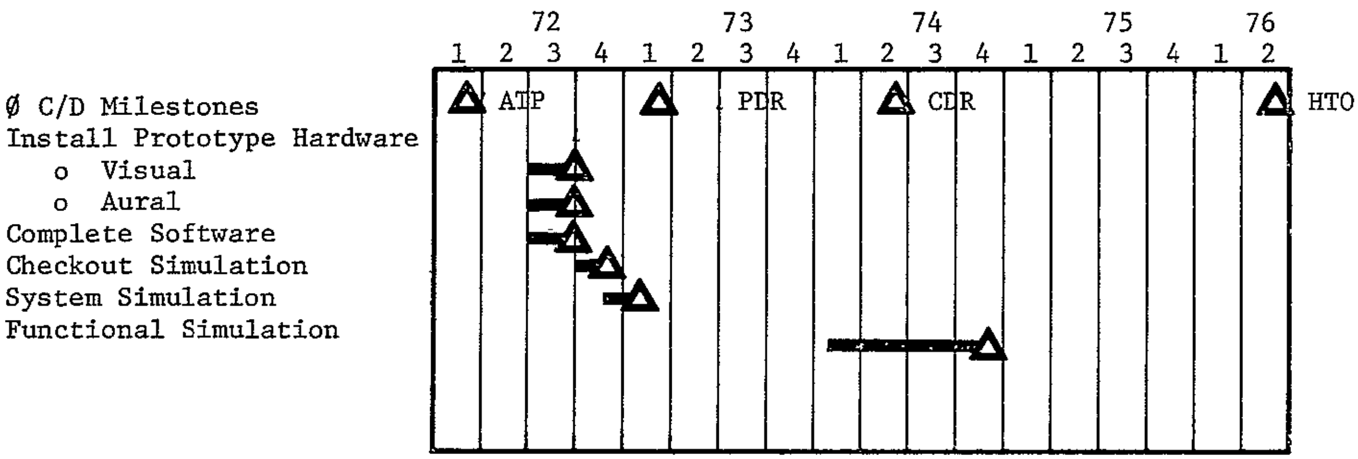
- o Human factory evaluation of visual data displays for emergency/caution/warning systems
- o Human factors evaluation of auditory devices for emergency/caution/warning systems
- o Establishment of criteria for warning methods based on degree of urgency (i.e., emergency/caution/warning)
- o Human factors evaluation of abort displays and controls devices.

JUSTIFICATION: Simulation techniques represent the best method of assisting in development of both visual and auditory warning systems. Operator response to an emergency situation is best evaluated by staging a realistic environment prior to and during emergency modes. This criteria can best be satisfied by real-time man-in-the-loop simulation using emergency/caution/warning system displays and controls in a realistic crew station.

DESCRIPTION: This simulation shall be performed using the engineering crew station simulator modified to include emergency/caution/warning system visual and aural displays. The hardware shall consist of prototype or simulated panel equipment with realistic indicator and/or alphanumeric displays. Aural displays shall exhibit realistic tones and signal levels. Simulation runs shall consist of measurement and evaluation of crew member reaction to emergency/caution/warning devices during vehicle operations in various mission phases and crew workload levels. The simulation computer shall be used to generate various message formats and sequences for crew member and human factors engineering evaluations in a real-time operational atmosphere. Operation of the emergency/caution/warning system shall be implemented on the simulation computer to be executed in real-time and shall be interfaced with the GN&C system simulation. Emergency/caution/warning devices may be initiated on command at various times during a simulation run by initiating inputs from a remote terminal. This task shall make use of existing GN&C simulation facilities and shall be performed at scheduled times concurrent with GN&C man-in-the-loop functional simulation activities.

FACILITY: The facility required for this task is a booster vehicle engineering crew station simulator coupled to a computer simulation capable of providing real-time man-in-the-loop simulations of all mission phases. A detailed description of the engineering crew station simulator is presented in Appendix D.

SCHEDULE: System simulation phase shall occur early in hardware development cycle to assist in development of emergency/caution/warning system hardware requirements. Functional simulation phase shall utilize prototype hardware to verify system operation and assist in emergency procedures development. Functional simulation should be operational before critical design review.



SRD 1.1.3.2.1

ORBITER CREW STATION CONTROLS & DISPLAYS DESIGN VERIFICATION

OBJECTIVE: The purpose of this task is to verify subsystem design and hard/ware software interface for nonavionic controls and displays that are driven by data bus information. Vehicle subsystems with displays and controls in this category include:

- o Electrical Power Subsystem
- o Hydraulic Power Subsystem
- o Environmental Control and Lift Support Subsystem
- o Propulsion and Propellant Management Subsystem
- o Auxiliary Propulsion Unit

Outputs of this simulation include:

- o Functional design acceptability of nonavionics controls and displays (part I)
- o Verify capability to manage subsystems functions (parts I and II)
- o Verification of displays and controls hardware/software interface (Part II)

JUSTIFICATION: Part I represents the first evaluation of nonavionics displays and controls for subsystems management in an operational environment. Functional acceptability of displays and controls interfacing with man-in-the-loop must be evaluated early to insure required design changes will minimize impact on program cost. A full simulation of actual flight operation provides deep technical penetration of the displays and controls design. Verification of hardware/software interface is necessary to insure compatibility of the displays and controls with the data management system in terms of scaling, data flow, mode switching, and general operating procedures.

DESCRIPTION: These simulations shall be performed in two parts. Part I is a verification of dedicated subsystems displays and controls design through use of real-time part-task simulation techniques. Part II is hardware/software verification of onboard subsystems controls and displays using actual flight software.

Part I - Verification of displays and controls design using prototype hardware is accomplished early in subsystem development so that any necessary hardware changes may be implemented at reasonable cost. Prototype dedicated subsystems displays that are driven by data bus information shall be installed in the engineering crew station simulator. Programs representing subsystem management logic shall be written and mechanized in the simulation computer. These subroutines shall be

cued to events in GN&C simulation programs for various mission phases. In this manner, dedicated subsystem displays may be evaluated in a dynamic crew station environment. Hardware prototypes of the following subsystems displays and controls shall be installed in the crew station mockup.

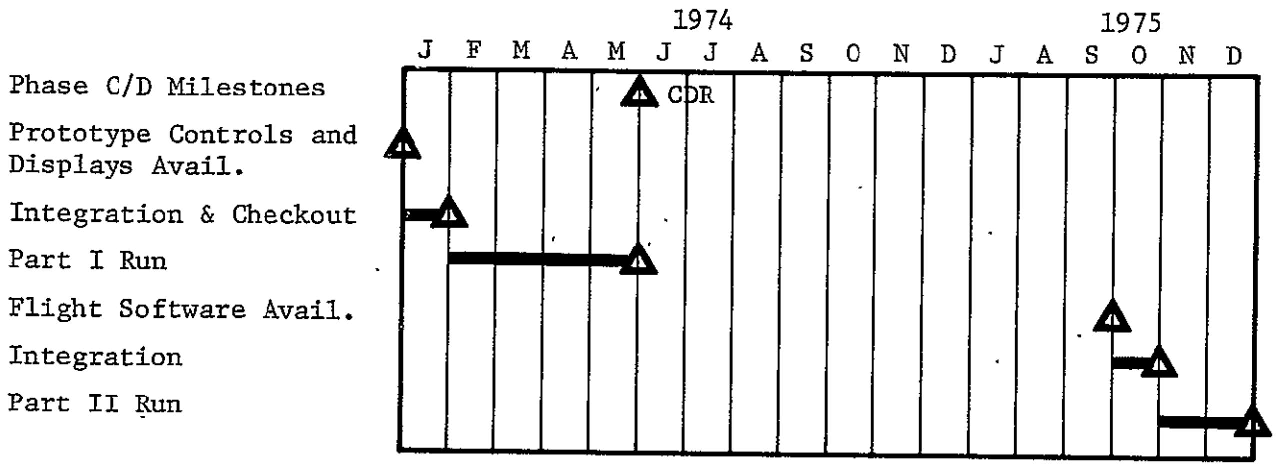
- o Orbit Maneuvering System
- o Fuel transfer and vent tank
- o ECLS
- o Electrical Displays
- o Fuel Cell & Power Distr.
- o Circuit Protection
- o Main engines
- o Attitude control propulsion system
- o Hydraulics displays
- o Propulsion (Air breathing)
- o APU and Hydraulic System Control

These instruments and controls shall be interfaced with the simulation computer through standard bilevel and analog/digital converter interface equipment.

Part II - As much actual subsystems hardware as practical shall be used in performing the controls and displays hardware/software verification. The orbiter vehicle systems-integration laboratory facility shall be used, which will include redundant operational avionics and hydraulics systems hardware, complete crew station simulator, and simulation computer. The simulation computer shall enable closed-loop performance of vehicle subsystems through a real-time simulation mission by providing vehicle models, environment models, G&N sensor models, and subsystem simulations (e.g., propulsion, ECLS, communications). The subsystems controls and displays hardware/software interface shall be evaluated by exercising controls in typical subsystem management routines.

FACILITY: Facility requirements range from the engineering crew station simulator and simulation computer with simulated displays and controls interface in part I, to incorporation of complete systems integration laboratory hardware facility in part II.

SCHEDULE: Part I is accomplished upon availability of prototype displays and controls (Feb. 1974). Part II is accomplished during first part of hardware/software validation (SRD 6.1.1) prior to horizontal flight.


1974
1975
J F M A M J J A S O N D J A S O N D
Phase C/D Milestones
CDR
Prototype Controls and Displays Avail.
Integration & Checkout
Part I Run
Flight Software Avail.
Integration
Part II Run

SRD 1.1.3.2.2

ORBITER VISUAL AND AUDITORY WARNING SYSTEM SIMULATION

OBJECTIVE: The objective of this task is to use simulation techniques to aid in development of visual and auditory warning systems in the orbiter vehicle. Outputs of the simulation shall include:

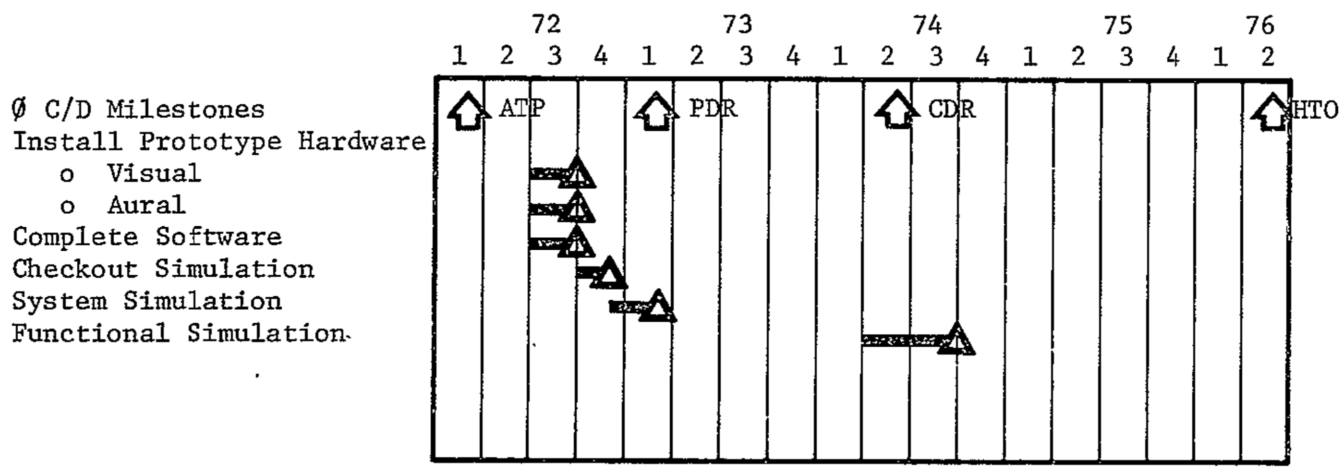
- o Human factors evaluation of visual data displays for emergency/caution/warning systems
- o Human factors evaluation of auditory devices for emergency/caution/warning systems
- o Establishment of criteria for warning methods based on degree of urgency (i.e., emergency/caution/warning)
- o Human factors evaluation of abort displays and controls devices.

JUSTIFICATION: Simulation techniques represent the best method of assisting in development of both visual and auditory warning systems. Operator response to an emergency situation is best evaluated by staging a realistic environment prior to and during emergency modes. This criteria can best be satisfied by real-time man-in-the-loop simulation using emergency/caution/warning system displays and controls in a realistic crew station.

DESCRIPTION: This simulation shall be performed using the engineering crew station simulator modified to include emergency/caution/warning system visual and aural displays. The hardware shall consist of prototype or simulated panel equipment with realistic indicator and/or alphanumeric displays. Aural displays shall exhibit realistic tones and signal levels. Simulation runs shall consist of measurement and evaluation of crew member reaction to emergency/caution/warning devices during vehicle operations in various mission phases and crew workload levels. The simulation computer shall be used to generate various message formats and sequences for crew member and human factors engineering evaluations in a real-time operational atmosphere. Operation of the emergency/caution/warning system shall be implemented on the simulation computer to be executed in real-time and shall be interfaced with the GN&C system simulation. Emergency/caution/warning devices may be initiated on command at various times during a simulation run by initiating inputs from a remote terminal. This task shall make use of existing GN&C simulation facilities and shall be performed at scheduled times concurrent with GN&C man-in-the-loop functional simulation activities.

FACILITY: The facility required for this task is a booster vehicle engineering crew station simulator coupled to a computer simulation capable of providing real-time man-in-the-loop simulations of all mission phases. A detailed description of the engineering crew station simulator is presented in Appendix D.

SCHEDULE: System simulation phase shall occur early in hardware development cycle to assist in development of emergency/caution/warning system hardware requirements. Functional simulation phase shall utilize prototype hardware to verify system operation and assist in emergency procedures development. Functional simulation should be operational before critical design review.



SRD 1.1.4.1.1

SATELLITE PLACEMENT/RETRIEVAL DEVICE DEVELOPMENT - ORBITER PAYLOAD

OBJECTIVE: The objective of this simulation is to aid in hardware design, procedures development, and training of flight crews in use of the telefactor device for satellite deployment and retrieval. Working full-scale mockups and a dynamic simulation shall be used to aid in development of hardware, procedures development, and training.

JUSTIFICATION: The requirement for this simulation is particularly unique because of a lack of experience in remotely controlling devices on a space vehicle for deployment, transfer, or retrieval of satellite or payload objects.

This task is pertinent to the Space Shuttle and will present a new set of operator requirements for performance of the various payload tasks. Therefore, it is desirable to carefully develop the required procedures and examine the proficiency of the crew in performing a number of remote control payload tasks.

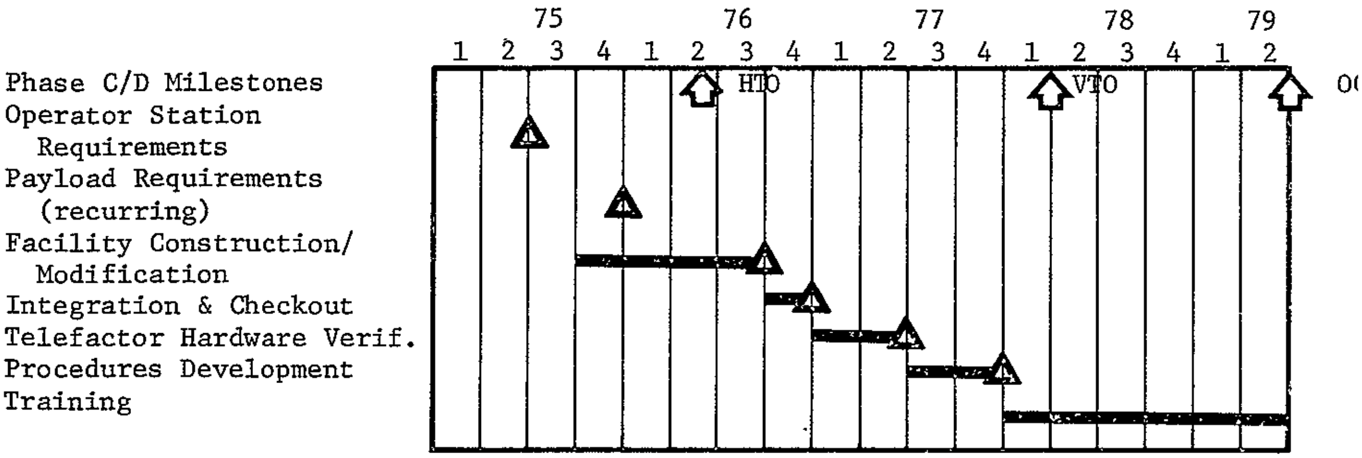
DESCRIPTION: Development of the telefactor device hardware, development of operational procedures, and training in telefactor use shall be accomplished with a simulation facility consisting of full-scale mockup of the orbiter remote docking and payload operation station and the full-scale operating telefactor mockup. Relative motions of satellite to vehicle, and telefactor command motion from the crew station shall be programmed on a simulation computer. The satellite or space station shall be a full-scale mockup mounted on a six degree of freedom motion base. Simulation problems shall consist of near term rendezvous and manipulations of the telefactor device for satellite capture, or performance of remotely controlled tasks on a variety of satellite or space station mockups.

The remote docking and payload operation station mockup will consist of functional replicas of required displays and controls in a closed cabin. Out-the-window views of the full-scale satellite mockups shall be viewed in proper prospective and shall portray a realistic environment, through motion base cues to the operator. Nominal motion base requirements shall be $\pm 45°$ pitch, roll and yaw angles with 70 foot longitudinal and 10 foot vertical and lateral translational travel.

The simulation computer shall be a digital device capable of being programmed in common scientific language. Vehicle to satellite relative motions shall be programmed to give the proper dynamic response to controller input.

FACILITY: The facility is represented by a computer driven motion base capable of moving a full-scale satellite mockup through a wide range of translational and small amplitude rotational motions.

SCHEDULE: The three phases consisting of hardware design, procedures development, and training activities shall carry on in parallel with the orbiter development program and shall extend throughout the operational phase as new mission payload requirements are developed.



SRD 1.1.5.1.1

BOOSTER CREW STATION SOFT MOCKUPS FOR GEOMETRY VERIFICATION

OBJECTIVE: This mockup is designed to display booster crew station geometry as an aid in determining design acceptability. The following outputs will be obtained:

- o Acceptability of crew accommodations and overall geometry
- o Location and arrangement of crew station controls and displays
- o Acceptability of crew station window design and compliance with visibility requirements

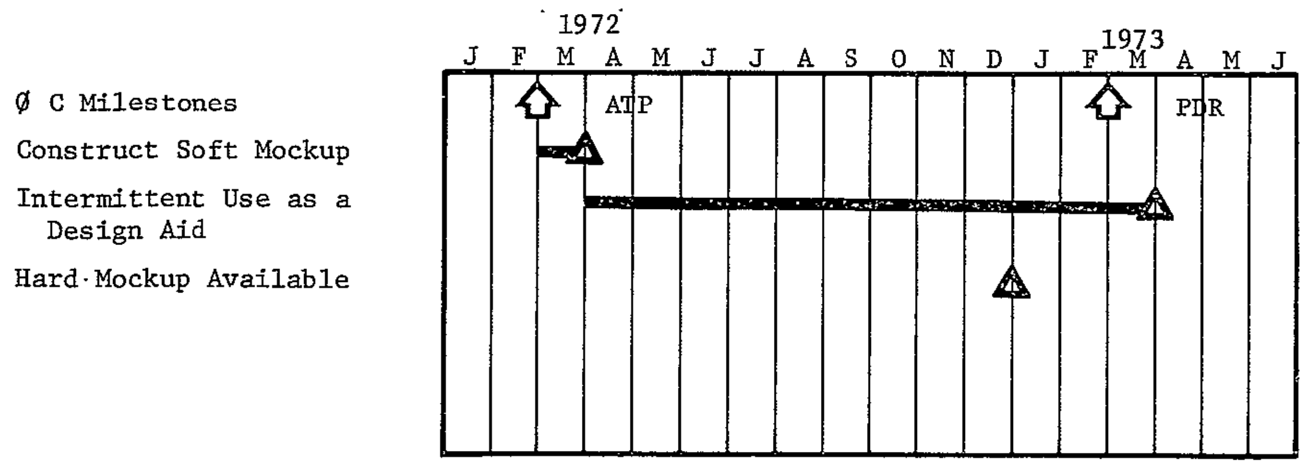
JUSTIFICATION: This mockup shall be constructed at minimum cost and may be economically altered to reflect proposed design changes. In this respect it is an inexpensive aid for visualizing crew station envelope design during early development stages.

DESCRIPTION: The mockup shall be constructed of soft paper/polystyrene foam material and assembled by taping or by other nonmetallic fasteners. Vehicle crew station drawings shall be used to construct the mockup interior to actual dimensional configuration. The mockups shall represent the area between the forward and aft pressure bulkheads. Evaluations of crew station acceptability may be made by crew station designers and integrators, human factors engineers, subsystems engineers, and flight crew members. Locations and sizing of vehicle controls and displays may be evaluated in order to define final layout of integrated crew station instrumentation.

Anthropometric considerations will be used in determining placement of vehicle controls, panels, and compartments, and sizing of crew seats. Measurements of out-the-window visual limits may be made for use in vehicle operational considerations, and to determine that design requirements are met.

FACILITY: Facility requirements consist of an area of sufficient size to contain the full-scale crew station, work area and visitors viewing area.

SCHEDULE: Mockup should be constructed early in Phase C when baseline crew station dimensions are known. The soft mockup shall remain in use until completion of the crew systems (one 'g') mockup.


1972
1973
J F M A M J J A S O N D J F M A M J
Ø C Milestones
ATP
PDR
Construct Soft Mockup
Intermittent Use as a Design Aid
Hard·Mockup Available

SRD 1.1.5.1.2

BOOSTER CREW SYSTEMS (ONE "G") MOCKUP

OBJECTIVE: The objective of this mockup is to aid in evaluation of crew systems equipment design by simulating the actual crew station arrangement. Areas of design evaluation which may be applied to this task include:

- o Equipment stowage and accessibility
- o Mobility aids and restraints
- o Ingress/egress provisions
- o Crew station lighting
- o Crew station accommodations

JUSTIFICATION: The mockup enables engineering and flight crew review of crew station interior arrangement and equipment configuration throughout vehicle design and development phase. This mockup enables a more positive approach to design problems by serving as a visual aid to crew station equipment designers in implementing their ideas.

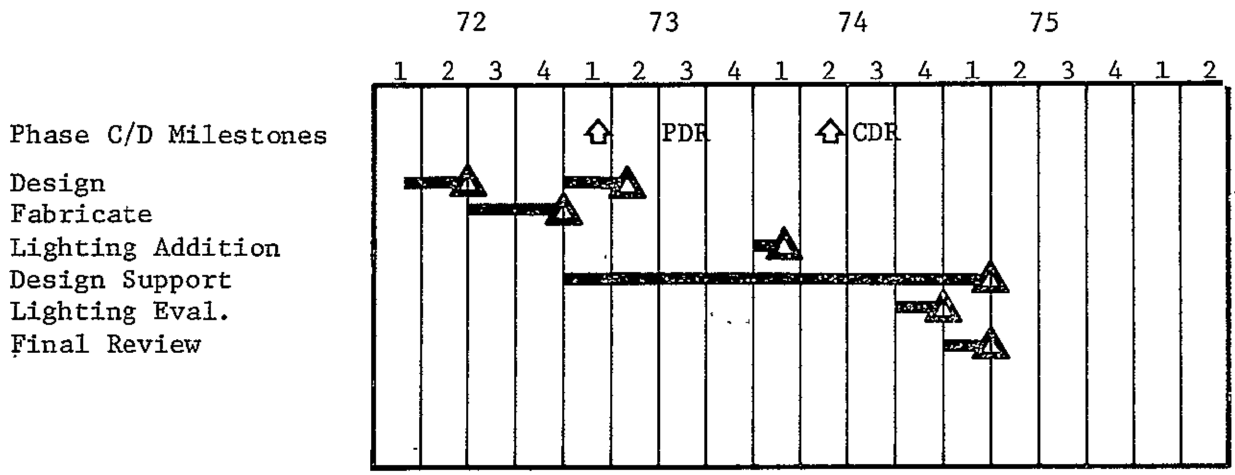
DESCRIPTION: Inputs for mockup construction shall originate from actual crew station design data and drawings. The mockup shall be built of durable materials from crew station drawings to provide an accurate representation of crew station geometry. Overall crew station mockup will include the crew station area, between the front and rear pressure bulkheads. The crew station mockup will be capable of being tilted 90° to vertical to study prelaunch ingress/egress and seating arrangements. All functional and nonfunctional equipment related to crew activities will be installed. Simulated functional equipment includes all hatches, lighting, crew and passenger mobility aids and restraints, storage facilities and seats. Nonfunctional equipment will include all panel displays, flight control equipment, and environmental control/life support subsystem equipment. Crew station accommodations may be alterable to evaluate different configurations dictated by various mission requirements. Interior crew station lighting shall be accurately simulated at the actual light sources with representative intensity and illumination of actual lighting system.

The mockup shall be used for periodic crew station reviews involving flight crew and design personnel. Evaluation of crew station design will be conducted using the crew station mockup to determine functional adequacy of crew accommodations. Preliminary evaluation will be made of crew's ability to move around within

the vehicle using mobility aids and restraints. Emergency ingress/egress of crew member and support personnel will be evaluated in vertical and horizontal crew station attitudes. Adequacy of crew station interior lighting will be evaluated.

FACILITY: The facility requirements consist of an area of sufficient size to contain the full-scale crew station, work area (including required shop equipment) and visitors viewing area.

SCHEDULE: Mockup construction will be complete by January 1973. Preliminary evaluation and design reviews will be conducted through 1973. Lighting will be added in January 1974. Lighting evaluation and final review will take place during 1st and 2nd quarters of 1975.



SRD 1.1.5.2.1

ORBITER CREW STATION SOFT MOCKUPS FOR GEOMETRY VERIFICATION

OBJECTIVE: This mockup is designed to display orbiter crew station geometry as an aid in determining design acceptability. The following outputs will be obtained:

- Acceptability of crew accommodations and overall geometry
- Location and arrangement of crew station controls and displays
- Acceptability of crew station window design and compliance with visibility requirements

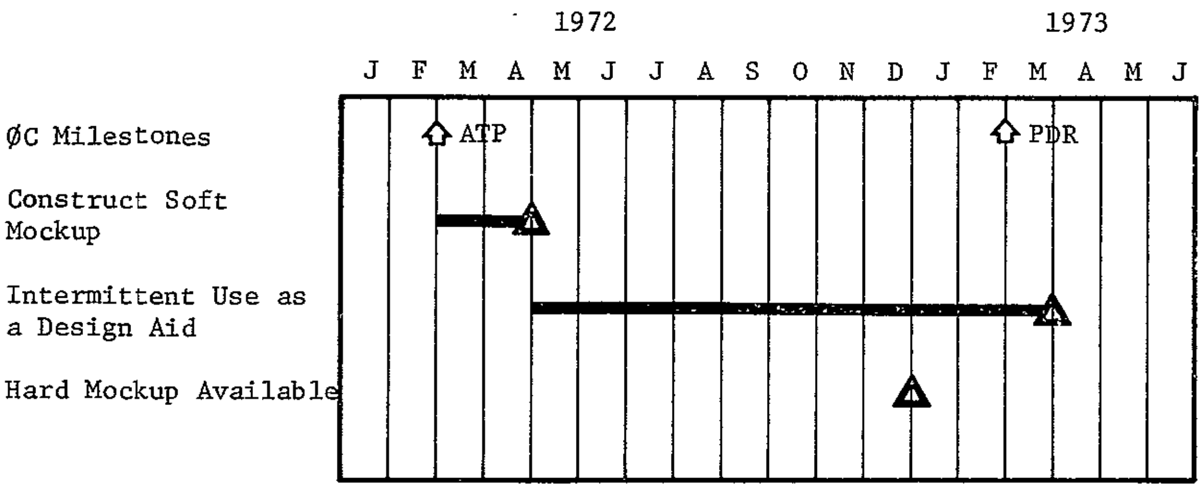
JUSTIFICATION: This mockup shall be constructed at minimum cost and may be economically altered to reflect proposed design changes. In this respect it is an inexpensive aid for visualizing crew station envelope design during early development stages.

DESCRIPTION: The mockup shall be constructed of soft paper/polystyrene foam material and assembled by taping or by other nonmetallic fasteners. Vehicle crew station drawings shall be used to construct the mockup interior to actual dimensional configuration. The soft mockup shall represent the total envelope of the crew cabin, airlock, food preparation, and waste management areas. Evaluations of crew station acceptability may be made by crew station designers and integrators, human factors engineers, subsystems engineers, and flight crew members. Locations and sizing of vehicle controls and displays may be evaluated in order to define final layout of integrated instrumentation.

Anthropometric considerations will be used in determining placement of vehicle controls, panels, and compartments, and sizing of crew seats. Measurements of out-the-window visual limits may be made for use in vehicle operational considerations, and to determine that design requirements are met.

FACILITY: Facility requirements consist of an area of sufficient size to contain the full-scale crew station, work area, and visitors viewing area.

SCHEDULE: Mockup should be constructed early in Phase C when baseline crew station dimensions are known. The soft mockup shall remain in use until completion of the crew systems (one "g") mockup.


1972
1973
J F M A M J J A S O N D J F M A M J
ØC Milestones
ATP
PDR
Construct Soft Mockup
Intermittent Use as a Design Aid
Hard Mockup Available

SRD 1.1.5.2.2

ORBITER CREW SYSTEMS (ONE "G") MOCKUP

OBJECTIVE: The objective of this mockup is to aid in evaluation of crew systems equipment design by simulating the actual crew station arrangement. Areas of design evaluation which may be applied to this task include:

- o Equipment stowage and accessibility
- o Mobility aids and restraints
- o Ingress/egress provisions
- o Crew station lighting
- o Crew station accommodations including:
  - o Waste management/hygiene
  - o Food management
  - o Sleep restraints
  - o Seating

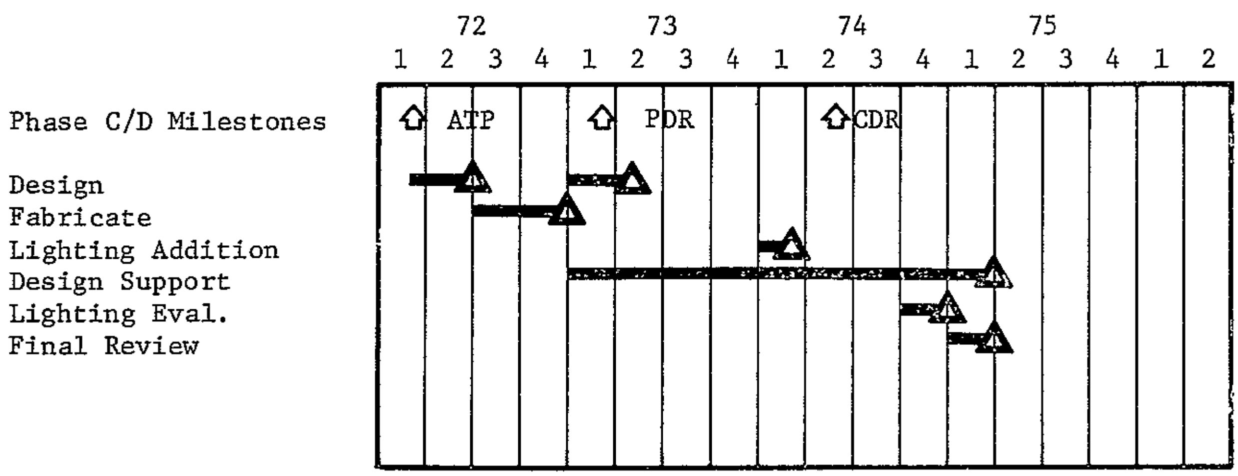
JUSTIFICATION: The mockup enables engineering and flight crew review of crew station interior arrangement and equipment configuration throughout vehicle design and development phase. This mockup enables a more positive approach to design problems by serving as a visual aid to crew station equipment designers in implementing their ideas.

DESCRIPTION: Inputs for mockup construction shall originate from crew station design data and drawings. The mockup shall be built of durable materials from crew station drawings to provide an accurate representation of crew station geometry. Overall crew station mockup will include the crew station area, airlock area, and food management and waste disposal areas. The crew station mockup will be capable of being tilted 90° to vertical to study prelaunch ingress/egress and seating arrangements. All functional and nonfunctional equipment related to crew activities will be installed. Simulated functional equipment includes all hatches, lighting, crew and passenger mobility aids and restraints, storage facilities and seats. Nonfunctional equipment will include all panel displays, flight control equipment, and environmental control/life support subsystem equipment. Crew station accommodations may be alterable to evaluate different configurations dictated by various mission requirements. Interior crew station lighting shall be accurately simulated at the actual light sources with representative intensity and illumination of actual lighting system.

The mockup shall be used for periodic crew station reviews involving flight crew and design personnel. Evaluation of crew station design will be conducted using the crew station mockup to determine functional adequacy of crew accommodations. Preliminary evaluation will be made of crew's ability to move around within the vehicle using mobility aids and restraints. Emergency ingress/egress of crew member and support personnel will be evaluated in vertical and horizontal crew station attitudes. Adequacy of crew station interior lighting will be evaluated.

FACILITY: The facility requirements consist of an area of sufficient size to contain the full-scale crew station, work area (including required shop equipment) and visitor's viewing area.

SCHEDULE: Mockup construction will be complete by January 1973. Preliminary evaluation and design reviews will be conducted through 1973. Lighting will be added in January 1974. Lighting evaluation and final review will take place during 1st and 2nd quarters of 1975.



SRD 1.1.6.1.1

BOOSTER WORKLOAD ANALYSIS

OBJECTIVE: The purpose of this simulation is to examine crew workload and task allocation through use of digital math models. Math models will be utilized to provide task performance data for any specified mission phase which may be identified for examination. Task performance data shall include such items as

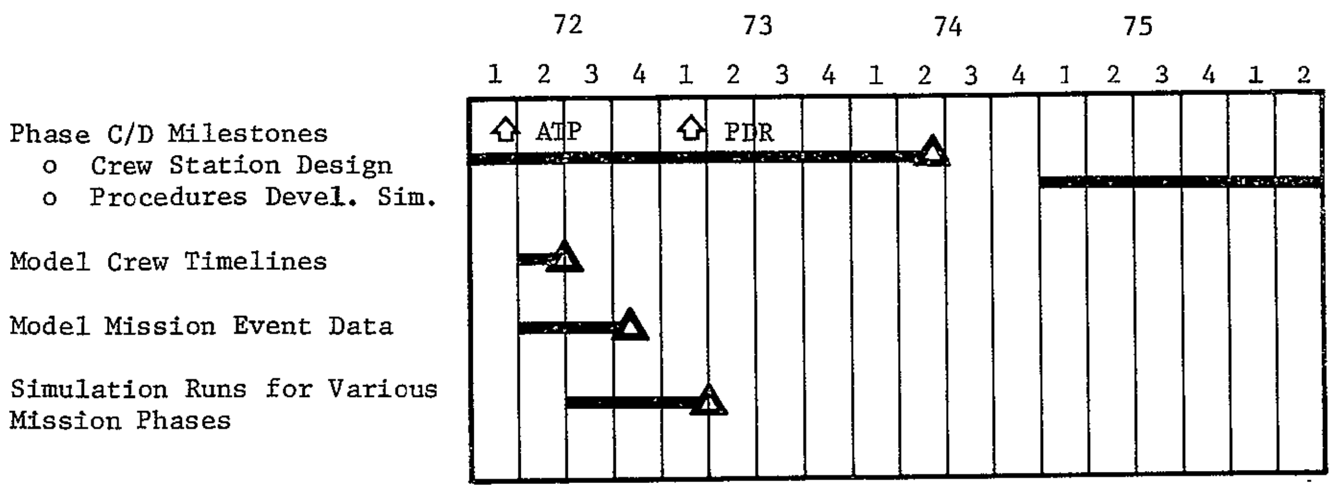
- o Crew member visual loading
- o Total and incremental times to accomplish task
- o Crew member motor activities
- o Crew-communication loading

JUSTIFICATION: The digital simulation model shall be used in the early phases of design to examine the adequacy of the crew station layout and workload division in terms of mission part-task performance requirements. This technique allows preliminary work to be accomplished in analyzing crew station layout and workload division without tying up costly man-in-the-loop simulation facilities. Results of these digital simulations may be later verified by man-in-the-loop simulation activity.

DESCRIPTION: Existing simulations may be modified to subsequently develop a crew workload digital model specifically designed for the Space Shuttle program. This will be a stochastic digital model with variable and parallel logic flow. This digital program allows simulation of simultaneous tasks, priority interrupts and degraded mode operations. The mode functions basically as an information store that is continually supplied with more current system information, subsequently updated to provide an output of probability statements regarding crew activities. The digital model can be used to obtain large amounts of data under controlled environmental conditions as defined in the program. Variables of interest may be systematically manipulated to determine their effect upon crew performance. Task loading data, performance times, degraded mode activities, operability, and degree of automation may be examined using this theoretical model designed for the Space Shuttle System. The model will provide the capability of varying crew size, task requirements, and design parameters to determine optimum allocation of tasks and distribution of workload during peak periods. Results of this simulation effort will be validated through manned simulation studies.

FACILITY: Facility requirements include a scientific digital computer capable of being programmed in common scientific language.

SCHEDULE: The simulation must be accomplished early in the design phase concurrently with crew station development and prior to crew procedures development.



SRD 1.1.6.1.2

BOOSTER WORKLOAD HUMAN FACTORS EVALUATION

OBJECTIVE: The purpose of this simulation is to evaluate critical control, perceptual, communications, and cognitive task requirements for all mission phases including normal two-man and single crew member operation capability with the autonomy which is characteristic of the Space Shuttle system. This simulation effort will be directed toward verification of output data from the crew workload analysis digital models described in SRD 1.1.6.1.1.

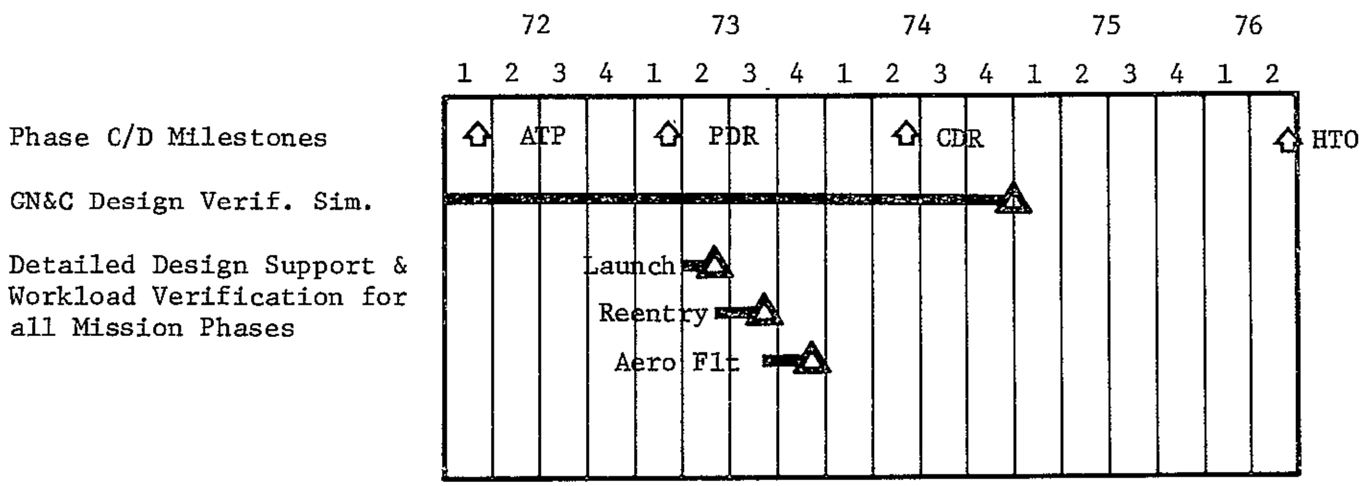
JUSTIFICATION: Man-in-the-loop simulations of various booster mission phases will enable analysis of individual phases in order to examine crew workload requirements and establish whether additional information is required or if task allocation should be revised. Actual man-in-the-loop simulation techniques provide the best method of verifying abilities of crew to adequately perform all vehicle control tasks.

DESCRIPTION: The use of a fixed-base simulator will be required for workload verification to examine crew activities for the various mission phases. The engineering high fidelity crew station simulator shall be used, and all time critical controls and displays shall be active. This degree of fidelity provides for crew performance of control tasks, communications tasks, and other responses requiring visual or aural stimuli or increasing vigilance performances. An out-the-window visual display presentation is required for special tasks, such as transition and terminal area flight control. The influence of other variables, such as auditory noise and illumination levels, shall be simulated.

The workload analysis shall verify GN&C and subsystem management crew tasks to provide desired level of onboard autonomy and capability of one-man vehicle operation. The possible requirement for increased automation will also be examined in the event there are periods of critical operations (e.g., reentry) when peak workloads may exceed the capacity of flight crew to perform the requisite tasks. The basic input data which will be utilized in this effort will be obtained from the crew workload digital models. The man-in-the-loop simulation will be designed to replicate the mission segments, environmental conditions, and task requirements which were utilized in the theoretical model. This validation technique will be used to verify crew performance data obtained from the model, e.g., peak loading periods, time-sharing of tasks, degraded modes of operation, and task allocation data.

FACILITY: The facility required is the engineering crew station simulator and simulation computer with software capability to provide real-time simulation of events occurring within all mission phases.

SCHEDULE: Simulation shall be performed after digital workload analysis and before final procedures development (concurrently with GN&C functional simulation activity).



SRD 1.1.6.1.3

BOOSTER CREW MISSION PROCEDURES DEVELOPMENT

OBJECTIVE: The purpose of this simulation is to aid in development of flight crew procedures for various mission segments on a part-task basis. The outputs of this effort are fully developed part-task flight crew procedures which will be integrated to form complete mission procedures. The development of flight crew procedures shall encompass (but not be limited to) the following mission segments and tasks:

- Ascent/abort
- Separation
- Entry
- Approach and landing
- Ferry

JUSTIFICATION: Simulation techniques have proven in past manned spacecraft programs to be excellent aids in developing crew procedures for normal and emergency mission operations. Capability to define, develop, and validate flight crew procedures in a real-time operating sequence contributes significantly to the efficiency of the procedures development task and assures a high degree of refinement.

DESCRIPTION: The task of flight crew procedures development is primarily an engineering effort utilizing the procedures training simulator facility. Inputs to the task include mission objectives and techniques, mission timelines, and vehicle subsystems operational data. Detailed procedures shall be developed for all mission phases through use of real-time part-task simulation techniques. Major portions of the simulation are simulation computer and software, crew station, and visual display system.

Simulation computer shall be a digital device of medium capacity capable of simulating vehicle operation for a given mission phase in real time. Simulation software required for a given mission phase will be subsystems math models, environment math models, simulated general flight software, and simulated guidance flight software peculiar to that mission phase. Subsystems math models shall provide initial conditions and real-time characteristic of each subsystem for the applicable mission phase. The output of these subsystem mechanizations shall interface with the crew station to provide proper instrument cues. Environment math models shall provide initial conditions and real-time solutions defining vehicle coordinate

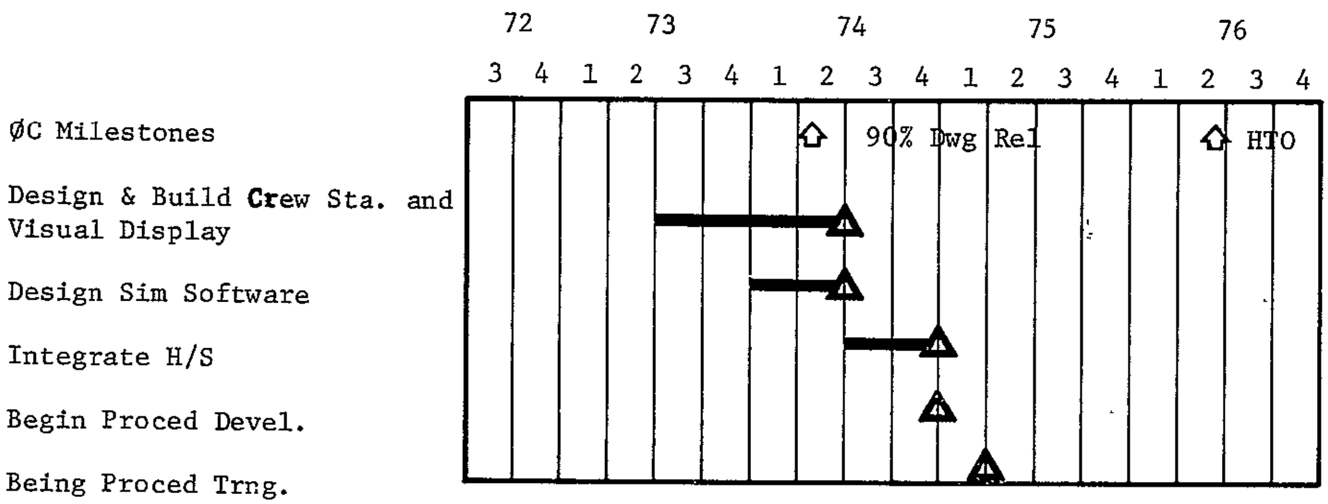
position, motions, and elapsed time based on mission phase. Environment math models shall be provided in sufficient detail to allow GN&C procedures to be conducted for each phase. Simulated flight software programs shall be adapted from existing programs developed for man-in-the-loop engineering functional simulations (SRD 1.1.1.1.2). General flight software includes routines for data bus management, subsystems management, and controls and displays operation. Guidance flight software will be organized by mission phase and the appropriate module will be used depending on the mission phase being simulated. An executive program will be required to perform initialization, timing, and synchronization operations.

The crew station will include all controls and displays required for Guidance Navigation & Control and time critical subsystems management tasks. The displays and controls will consist of actual, or exact working replicas of booster crew station geometry, lighting, and accommodations. Use of actual Shuttle hardware in the crew station will be minimized. The crew station will be capable of being rotated to a vertical orientation for prelaunch and launch procedures development.

A high-resolution, virtual-image projection system utilizing closedccircuit color television will provide out-the-window views. The views will be generated from models and mockups to simulate actual visual situations including starfields, near-earth horizon cloud cover, and terrain model with airfield-runway views.

FACILITY: The simulation facility for flight crew procedures development and procedures training (SRD 1.2.1.2) shall be used to fulfill requirements of both tasks. The facility basically consists of a medium fidelity crew station mockup and out-the-window displays, both interfaced to a medium-sized scientific computer. A minimum of actual vehicle hardware and simulated flight software shall be used in the simulation task. The simulator shall be located on-site at the NASA crew operations and training facility. The simulator shall be similar in many respects to the engineering crew station simulator described in Appendix D.

SCHEDULE: Flight crew procedures development effort is required to be complete prior to first horizontal flight (June 1976) and is a continuing effort dictated by procedures changes in mission types.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Being Proced Trng.

SRD 1.1.6.2.1

ORBITER WORKLOAD ANALYSIS

OBJECTIVE: The purpose of this simulation is to examine crew workload and task allocation through use of digital math models. Math models will be utilized to provide task performance data for any specified mission phase which may be identified for examination. Task performance data shall include such items as

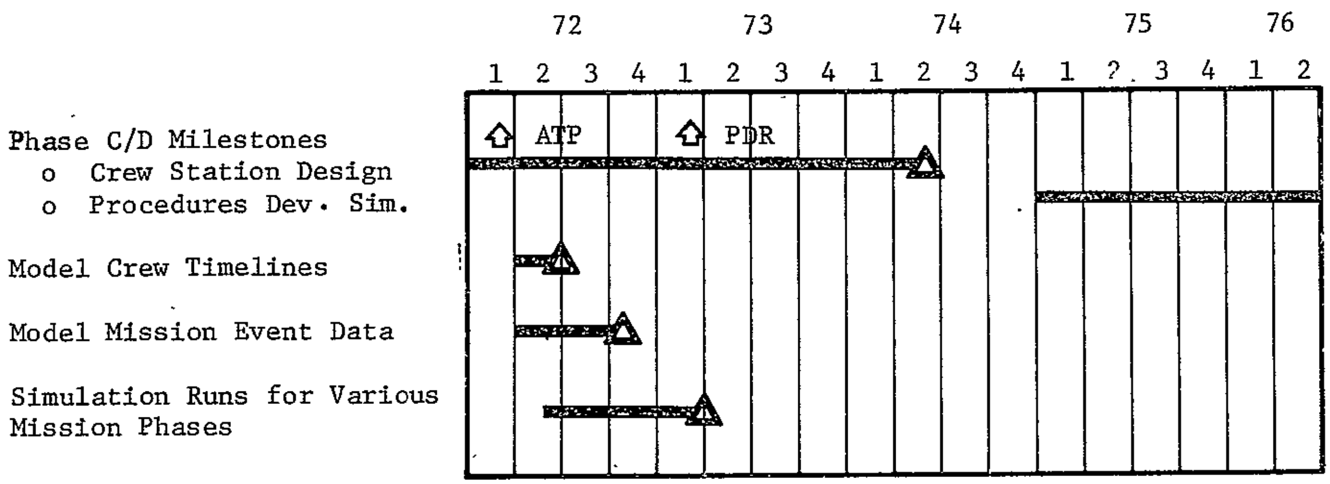
- o Crew member visual loading
- o Total and incremental times to accomplish task
- o Crew member motor activities
- o Crew-communication loading

JUSTIFICATION: The digital simulation model shall be used in the early phases of design to examine the adequacy of the crew station layout and workload division in terms of mission part-task performance requirements. This technique allows preliminary work to be accomplished in analyzing crew station layout and workload division without tying up costly man-in-the-loop simulation facilities. Results of these digital simulations may be later verified by man-in-the-loop simulation activity.

DESCRIPTION: Existing simulations may be modified to subsequently develop a crew workload digital model specifically designed for the Space Shuttle program. This will be a stochastic digital model with variable and parallel logic flow. This digital program allows simulation of simultaneous tasks, priority interrupts, and degraded mode operations. The model functions basically as an information store that is continually supplied with more current system information, subsequently updated to provide an output of probability statements regarding crew activities. The digital model can be used to obtain large amounts of data under controlled environmental conditions as defined in the program. Variables of interest may be systematically manipulated to determine their effect upon crew performance. Task loading data, performance times, degraded mode activities, operability, and degree of automation may be examined using this theoretical model designed for the Space Shuttle system. The model will provide the capability of varying crew size, task requirements, and design parameters to determine optimum allocation of tasks and distribution of workload during peak periods. Results of this simulation effort will be validated through manned simulation studies.

FACILITY: Facility requirements include a scientific digital computer capable of being programmed in common scientific language.

SCHEDULE: The simulation must be accomplished early in the design phase concurrently with crew station development and prior to crew procedures development.



SRD 1.1.6.2.2

ORBITER WORKLOAD HUMAN FACTORS EVALUATION

OBJECTIVE: The purpose of this simulation is to evaluate critical control, perceptual, communications, and cognitive task requirements for all mission phases including normal two-man and single operator control capability with the autonomy which is characteristic of the Space Shuttle system. This simulation effort will be directed toward verification of output data from the crew workload analysis digital models described in SRD 1.1.6.2.1.

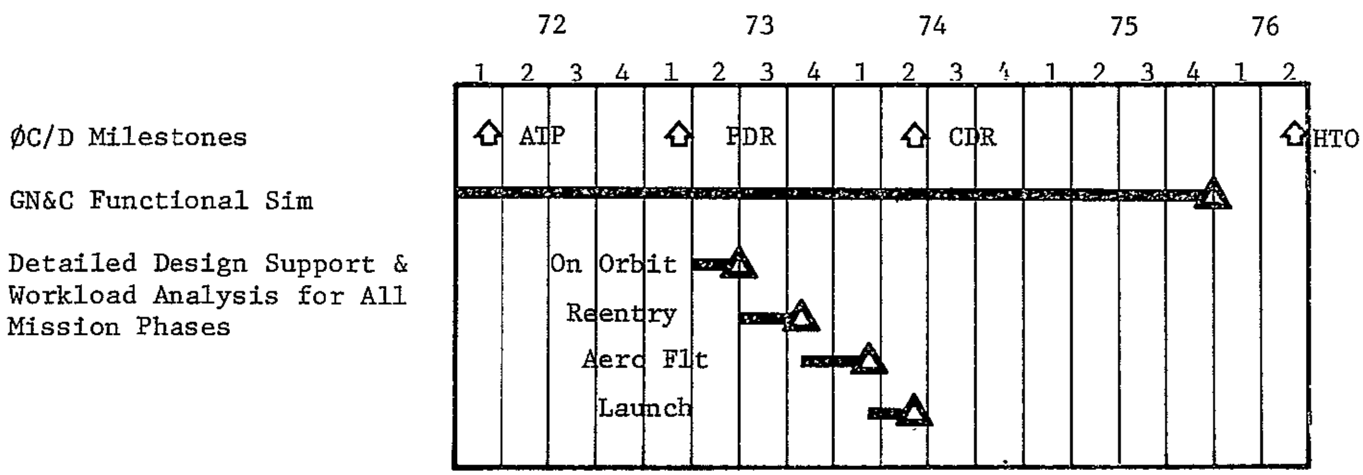
JUSTIFICATION: Man-in-the-loop simulations of various Orbiter mission phases will enable analysis of individual phases in order to examine crew workload requirements and establish if additional information is required or if task allocation should be revised. Actual man-in-the-loop simulation techniques provide the best method of verifying abilities of crew to adequately perform all vehicle control tasks.

DESCRIPTION: The use of a fixed-base simulator will be required for workload verification to examine crew activities for the various mission phases. The engineering high fidelity crew station simulator shall be used, and all time-critical controls and displays shall be active. This degree of fidelity provides for crew performance of control tasks, communications tasks, and other responses requiring visual or aural stimuli or increasing vigilance performances. An out-the-window visual display presentation is required for special tasks, such as rendezvous, docking, reentry, and terminal area flight control. The influence of other variables, such as auditory noise and illumination levels shall be simulated.

The workload analysis shall verify GN&C and subsystem management crew tasks to provide desired level of on-board autonomy and capability of one-man vehicle operation. The possible requirement for increased automation will also be examined in the event there are periods of critical operations (e.g., reentry) when peak workloads may exceed the capacity of flight crew to perform the requisite tasks. The basic input data which will be utilized in this effort will be obtained from the crew workload digital models. The man-in-the-loop simulation will be designed to replicate the mission segments, environmental conditions, and task requirements which were utilized in the theoretical model. This validation technique will be used to verify crew performance data obtained from the model, e.g., peak loading periods, time-sharing of tasks, degraded modes of operation, and task allocation data.

FACILITY: The facility required is the fixed base engineering crew station and simulation computer with software capability to provide real-time simulation of events occurring within all mission phases.

SCHEDULE: Simulation shall be performed after digital workload analysis and before final procedures development (concurrently with GN&C functional simulation activity).



SRD 1.1.6.2.3

ORBITER CREW MISSION PROCEDURES DEVELOPMENT

OBJECTIVE: The purpose of this simulation is to aid in development of flight crew procedures for various mission segments on a part-task basis. The outputs of this effort are fully developed part-task flight crew procedures which will be integrated to form complete mission procedures. The development of flight crew procedures shall encompass (but not be limited to) the following mission segments and tasks:

- o Ascent/abort
- o Separation
- o Rendezvous and Docking
- o Entry
- o Approach and Landing
- o Ferry

JUSTIFICATION: Simulation techniques have proven in past manned spacecraft programs to be excellent aids in developing crew procedures for normal and emergency mission operations. Capability to define, develop, and validate flight crew procedures in a real-time operating sequence contributes significantly to the efficiency of the procedures development task and assures a high degree of refinement.

DESCRIPTION: The task of flight crew procedures development is primarily an engineering effort utilizing the procedures training simulator facility. Inputs to the task include mission objectives and techniques, mission timelines, and vehicle subsystems operational data. Detailed procedures shall be developed for all mission phases through use of real-time, part-task simulation techniques. Major portions of the simulation are simulation computer and software, crew station, and visual display system.

Simulation computer shall be a digital device of medium capacity capable of simulating vehicle operation for a given mission phase in real time. Simulation software required for a given mission phase will be subsystems math models, environment math models, simulated general flight software, and simulated guidance flight software peculiar to that mission phase. Subsystems math models shall provide initial conditions and real-time characteristic of each subsystem for the applicable mission phase. The output of these subsystem mechanizations shall interface with the crew station to provide proper instrument cues. Environment math

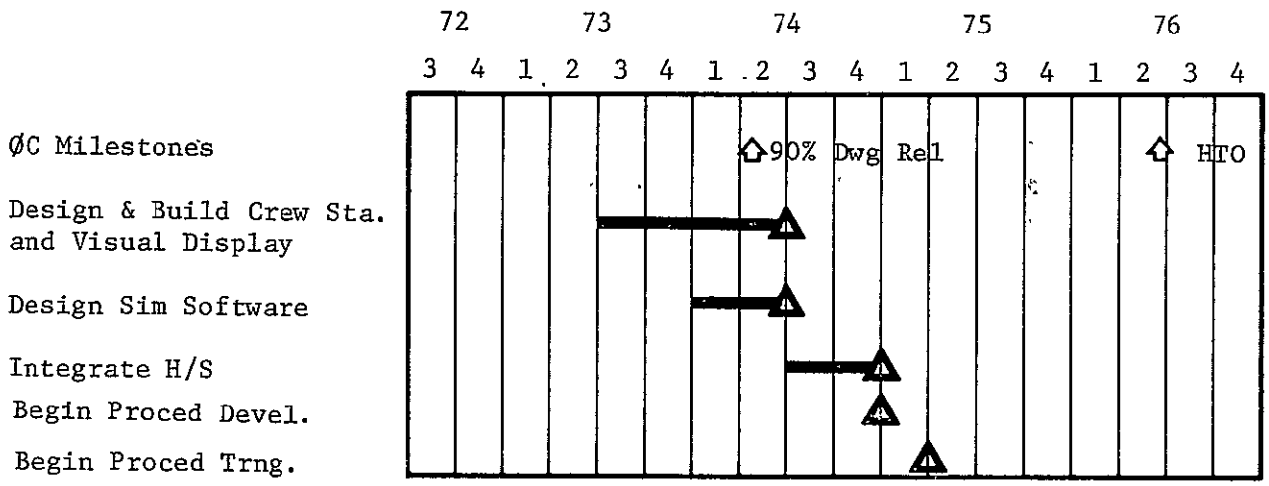
models shall provide initial conditions and real-time solutions defining vehicle coordinate position, motions, and elapsed time based on mission phase. Environment math models shall be provided in sufficient detail to allow GN&C procedures to be conducted for each phase. Simulated flight software programs shall be adapted from existing programs developed for man-in-the-loop engineering functional simulations (SRD 1.1.1.1.2). General flight software includes routines for data bus management, subsystems management, and controls and displays operation. Guidance flight software will be organized by mission phase and the appropriate module will be used depending on the mission phase being simulated. An executive program will be required to perform initialization, timing, and synchronization operations.

The crew station will include all controls and displays required for Guidance Navigation & Control and time-critical subsystems management tasks. The displays and controls will consist of actual, or exact working replicas of Orbiter crew station geometry, lighting, and accommodations. Use of actual Shuttle hardware in the crew station will be minimized. The crew station will be capable of being rotated to a vertical orientation for prelaunch and launch procedures development.

A high-resolution, virtual-image projection system utilizing closed circuit color television will provide out-the-window views. The views will be generated from models and mockups to simulate actual visual situations including starfields, near-earth horizon cloud cover, and terrain model with airfield-runway views. Gimbaled scale models of target vehicles and CCTV cameras provide out-the-window presentations for rendezvous and docking procedures development.

FACILITY: The simulation facility for flight crew procedures development and procedures training (SRD 1.2.2.2) shall be used to fulfill requirements of both tasks. The facility basically consists of a medium fidelity crew station mockup and out-the-window displays, both interfaced to a medium-sized scientific computer. A minimum of actual vehicle hardware and simulated flight software shall be used in this simulation task. The simulator shall be located on-site at the NASA crew operations and training facility. The simulator shall be similar in many respects to the engineering crew station simulator described in Appendix D.

SCHEDULE: Flight crew procedures development effort is required to be complete prior to first horizontal flight (June 1976) and is a continuing effort dictated by procedures changes in various mission types.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Design Sim Software
Integrate H/S
Begin Proced Devel.
Begin Proced Trng.

SRD 1.2.1.1
ONE-'G' FAMILIARIZATION AND TRAINING SIMULATION - BOOSTER

OBJECTIVE: The one 'g' mockup shall be provided by the contractor to serve as a familiarization and preliminary training device. Familiarization and preliminary training in crew accommodations, mobility aids, normal and energency ingress/egress operations and other special procedural tasks shall be conducted as applicable to vertical or horizontal orientation of the crew station. Output of this training simulation will consist of:

- o Crew station familiarization for new flight crew members
- o Preliminary training for zero-g and neutral bouyancy training
- o Retraining required as a result of changes in crew procedures or crew station accommodations
- o Recurrent training of flight crew as required

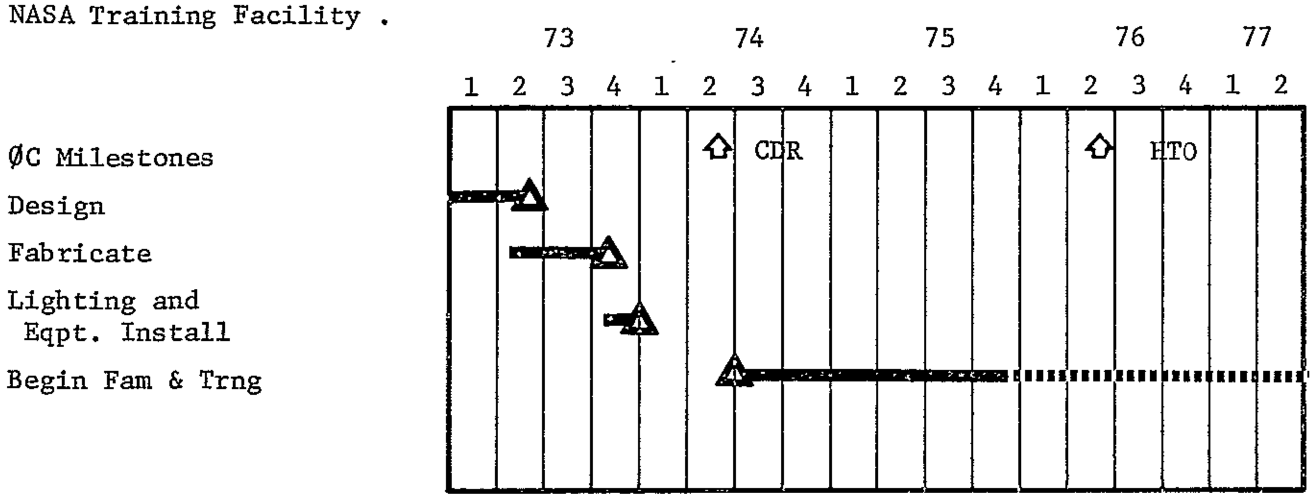
JUSTIFICATION: The one-'g' mockup required for crew-station development functions as a static familiarization training device for flight crew members prior to dynamic part-task and full mission training simulations. The static crew station trainer will provide familiarization of crew station accommodations without tying up procedures trainers and mission trainers which will have high occupancy costs and critically high usage rates.

DESCRIPTION: The crew station training mockup shall be used as a preliminary familiarization device prior to simulation training activity, as a familiarization device for new flight crew members and as a reference for procedures changes.

Overall crew station mockup shall include the crew station area enclosed by the forward and aft pressure bulkheads. The crew station mockup will be capable of being tilted 90° to vertical. Functional and non-functional equipment will be installed. Simulated functional equipment includes all hatches, crew and passenger mobility aids and restraints, storage facilities, seats and food and waste management equipment storage facilities. Non-functional equipment will include all panel displays, flight control equipment, food and waste management equipment, and environmental control/life support subsystem equipment. Inputs for mockup contruction shall originate from actual crew station design data and drawings. Interior crew station lighting shall be accurately simulated at the actual light sources with intensity and illumination representative of actual lighting.

FACILITY: The crew station mockup shall be located adjacent to procedures trainers and mission simulators at the NASA flight crew training facility to provide support for flight crew training activity.

SCHEDULE: Mockup will be constructed or modified to latest shuttle crew station interior configuration and will be available by June 1974 for support on-site at NASA Training Facility .



SRD 1.2.1.2

BOOSTER PROCEDURES TRAINING SIMULATION

OBJECTIVE: The objective of this simulation is to provide detailed subsystems familiarization and procedures training for the flight crew on a part-task basis for the following mission phases:

- o Launch Abort
- o Entry & Transition
- o Terminal Approach & Landing

The familiarization and training tasks will improve flight crew proficiency in Guidance, Navigation and Control functions and subsystems management. The task will be accomplished in a simulated booster crew station equipped with functional replicas of actual controls and displays and out-the-window views.

JUSTIFICATION: The aspects of increased onboard autonomy and the dual roles of spacecraft and aircraft function require a detailed knowledge of subsystems operation and mission procedures. This knowledge may be obtained by a training simulation program comparable to past programs.

DESCRIPTIONS: The procedures simulator is a fixed base crew station of medium fidelity interfaced with a hybrid computer to provide part-task training in vehicle subsystems and operational procedures for a given mission phase. Major hardware components required for procedures simulation are crew station, visual display system, computer and interface.

The crew station will include all displays and controls required for GN&C and time critical subsystems management tasks. The displays and controls will consist of actual or exact functioning replicas of flight equipment. Crew station geometry, lighting and accommodations will resemble actual booster vehicle configuration. Use of actual hardware in the crew station will be minimized. The crew station will be capable of being rotated to a vertical orientation for prelaunch and launch procedures training.

A high-resolution virtual-image projection system utilizing closed circuit color television will provide out-the-window views. The views will be generated from models and mockups to simulate actual visual situations including starfields, near-earth horizon, cloud cover and terrain model with airfield and runway views.

The simulation computer shall be a medium size digital device capable of being programmed in common scientific language.

Major software programs required for procedures training include vehicle subsystems program, environmental program, simulated flight software and executive.

Subsystems Programs - These models represent operation of each vehicle subsystem in sufficient detail to provide all required cues to the trainee. The models will be derived from engineering models used in subsystems analysis and functional simulations during the engineering development phase.

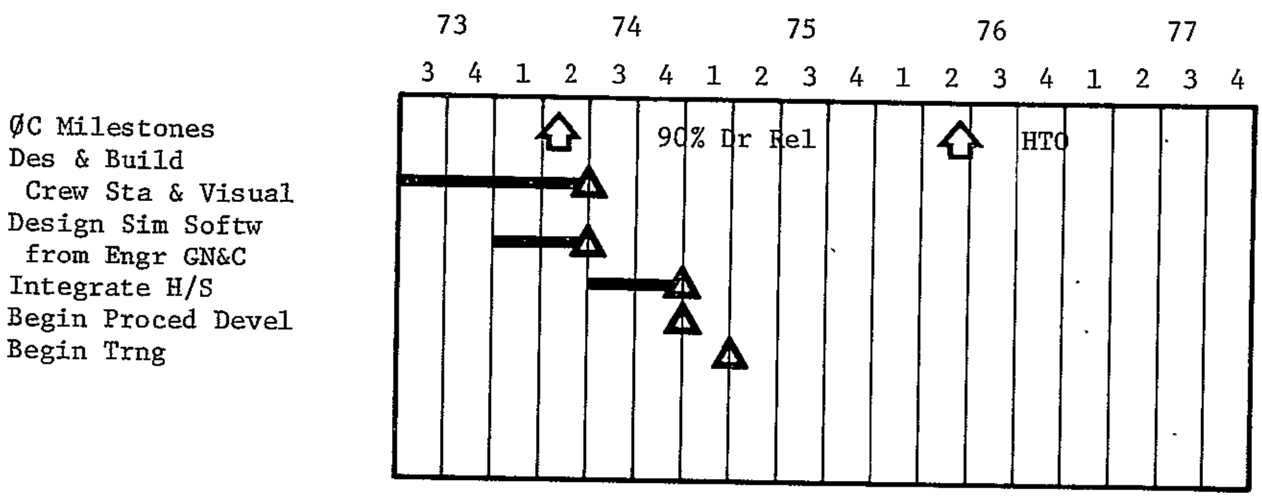
Environmental Program - These models represent the dynamic environment in which the vehicle operates and the interaction between vehicle and environment. These models will be derived from environment simulations used in man-in-the-loop functional simulations. The models shall employ rigid body dynamics, linear aerodynamic models and simplified mass properties.

Vehicle Flight Software - The simulated flight software consisting of a series of modularized subprograms coded to operate on the simulation computer will be used to provide data management system control of vehicle subsystems. In addition to the control module, off line utility modules, navigation module and various mission phase guidance modules will be used depending on the particular phase of training being conducted. The flight software will be kept current with configuration changes and "mission peculiar" software requirements.

Executive - The simulation system executive program will provide a real-time operating system for the simulation and other required program control modes. The executive will organize to provide the capability to perform part-task training by mission phase.

FACILITY: The simulation facility for flight crew procedures development (SRD 1.1.6.1.2) and procedures training shall be used to fulfill requirements of both tasks. The facility basically consists of a medium fidelity crew station mockup and out-the-window displays, both interfaced to a medium sized scientific computer. A minimum of actual vehicle hardware and simulated flight software shall be used in this simulation task. The simulator shall be located on site at the NASA crew operations and training facility.

SCHEDULE: The procedures training simulation effort is required prior to first horizontal flight scheduled for June 1976. Training activities should begin by April 1975, in order to provide a maximum of 12 months training before first flight.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SRD 1.2.2.1

ONE 'G' FAMILIARIZATION AND TRAINING SIMULATION - ORBITER

OBJECTIVE: The one 'g' mockup shall be provided by the contractor to serve as a familiarization and preliminary training device. Familiarization and preliminary training in crew accommodations, mobility aids, normal and emergency ingress/egress operations and other special procedural tasks shall be conducted as applicable to vertical or horizontal orientation of the crew station. Output of this training simulation will consist of:

- o Crew station familiarization for new flight crew members
- o Preliminary training for zero-g and neutral buoyancy training
- o Retraining required as a result of changes in crew procedures or crew station accommodations
- o Recurrent training of flight crew as required

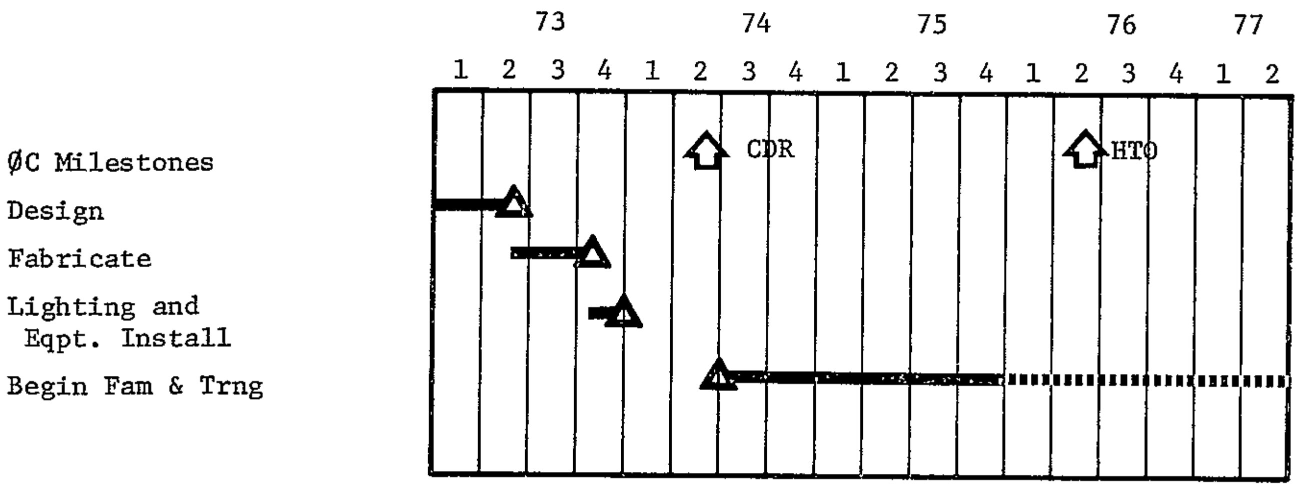
JUSTIFICATION: The one 'g' mockup required for crew station development functions as a static familiarization training device for flight crew members prior to dynamic part task and full mission training simulations. The static crew station trainer will provide familiarization of crew station accommodations without tying up procedures trainers and mission trainers which will have high occupancy costs and critically high usage rates.

DESCRIPTION: The crew station training mockup shall be used as a preliminary familiarization device prior to zero-g, high-g, and neutral buoyancy training activity, as a familiarization device for new flight crew members, as a reference for procedures changes and retraining and refamiliarization of personnel.

Overall crew station mockup shall include the crew station area, airlock area including payload tunnel, and waste management and food storage areas. The crew station mockup will be capable of being tilted 90° to vertical. Functional and non-functional equipment will be installed. Simulated functional equipment includes all hatches, crew and passenger mobility aids and restraints, storage facilities, seats, and food and waste management equipment storage facilities. Non-functional equipment will include all panel displays, flight control equipment, food and waste management equipment, and environmental control/life support subsystem equipment. Inputs for mockup construction shall originate from actual crew station design data and drawings. Interior crew station lighting shall be accurately simulated at the actual light sources with intensity and illumination representative of actual lighting.

FACILITY: The crew station mockup shall be located adjacent to procedures trainers and mission simulators at the NASA flight crew training facility to provide support for flight crew training activity.

SCHEDULE: Mockup will be constructed or modified to latest Shuttle crew station interior configuration and will be available by June 1974 for support on-site at NASA Training Facility.



SRD 1.2.2.2

ORBITER PROCEDURES TRAINING SIMULATION

OBJECTIVE: The objective of this simulation is to provide detailed subsystems familiarization and procedures training for the flight crew on a part-task basis for the following mission phases:

- o Launch abort
- o On orbit
- o Rendezvous & Docking
- o Entry & Transition
- o Terminal Approach & Landing

The familiarization and training tasks will improve flight crew proficiency in Guidance, Navigation and Control functions and subsystems management. The task will be accomplished in a simulated orbiter crew station equipped with functional replicas of actual controls and displays and out-the-window views.

JUSTIFICATION: The aspects of increased onboard autonomy and the dual roles of spacecraft and aircraft function require a detailed knowledge of subsystems operation and mission procedures. This knowledge may be obtained by a training simulation program comparable to past programs.

DESCRIPTIONS: The procedures simulator is a fixed base crew station of medium fidelity interfaced with a hybrid computer to provide part-task training in vehicle subsystems and operational procedures for a given mission phase. Major hardware components required for procedures simulation are crew station, visual display system, computer and interface.

The crew station will include all displays and controls required for GN&C and time critical subsystems management tasks. The displays and controls will consist of actual or exact functioning replicas of flight equipment. Crew station geometry, lighting, and accommodations will resemble actual orbiter vehicle configuration. Use of actual hardware in the crew station will be minimized. The crew station will be capable of being rotated to a vertical orientation for prelaunch and launch procedures training.

A high-resolution virtual-image projection system utilizing closed circuit color television will provide out-the-window views. The views will be generated from models and mockups to simulate actual visual situations including starfields, near-earth horizon, cloud cover, and terrain model with airfield and runway views.

Gimballed scale models of target vehicles and CCTV cameras provide six-degree-of-freedom out-the-window presentations for rendezvous and docking procedures training.

The simulation computer shall be a medium size digital device capable of being programmed in common scientific language.

Major software programs required for procedures training include vehicle subsystems program, environmental program, simulated flight software, and executive.

Subsystems Programs - These models represent operation of each vehicle subsystem in sufficient detail to provide all required cues to the trainee. The models will be derived from engineering models used in subsystems analysis and functional simulations during the engineering development phase.

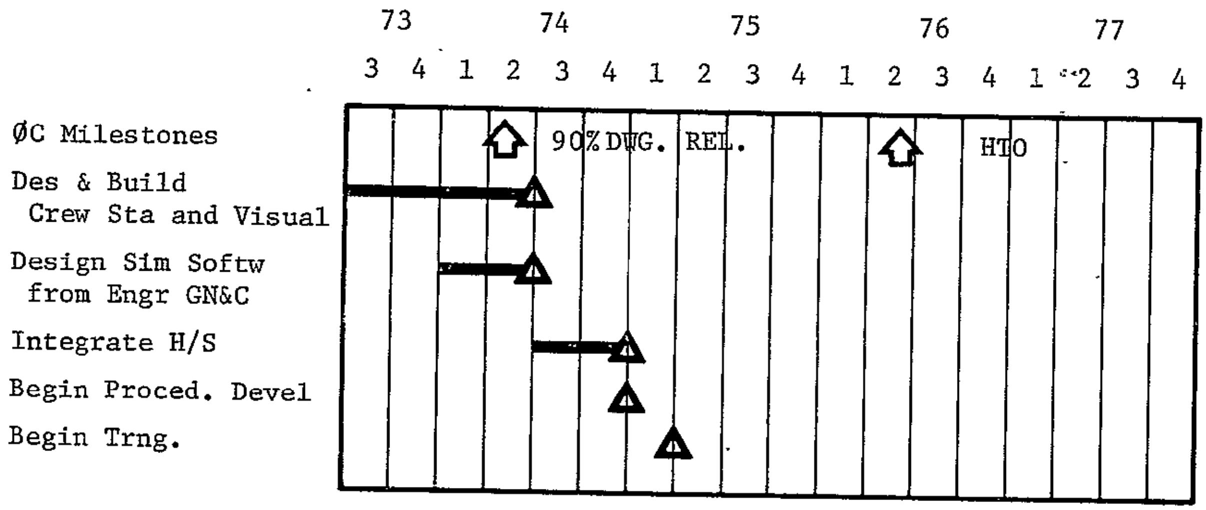
Environmental Program - These models represent the dynamic environment in which the vehicle operates and the interaction between vehicle and environment. These models will be derived from environment simulations used in man-in-the-loop functional simulations. The models shall employ rigid body dynamics, linear aerodynamic models, and simplified mass properties.

Vehicle Flight Software - The simulated flight software consisting of a series of modularized subprograms coded to operate on the simulation computer will be used to provide data management system control of vehicle subsystems. In addition to the control module, off line utility modules, navigation module, and various mission-phase guidance modules will be used depending on the particular phase of training being conducted. The flight software will be kept current with configuration changes and "mission peculiar" software requirements.

Executive - The simulation system executive program will provide a real-time operating system for the simulation, and other required program control modes. The executive will organize to provide the capability to perform part-task training by mission phase.

FACILITY: The simulation facility for flight crew procedures development (SRD 1.1.6.2.2) and procedures training shall be used to fulfill requirements of both tasks. The facility basically consists of a medium fidelity crew station mockup and out-the-window displays, both interfaced to a medium sized scientific computer. A minimum of actual vehicle hardware and simulated flight software shall be used in this simulation task. The simulator shall be located on site at the NASA crew operations and training facility.

SCHEDULE: The procedures training simulation effort is required prior to first horizontal flight scheduled for June 1976. Training activities should begin by April 1975, in order to provide a maximum of 12 months training before first flight.



SRD 1.2.3.1

MISSION TRAINING SIMULATION - COMBINED BOOSTER & ORBITER

OBJECTIVE: The objective of this simulation is to conduct total-task training of booster and orbiter flight crews and flight control personnel. The booster and orbiter mission simulators will provide high-fidelity environment and realistic vehicle systems operation for all mission phases as a continuous simulation. Outputs of this simulation are basic and recurrent mission training tasks required to maintain proficiency in subsystems management and GN&C procedures for orbiter and booster total mission operation. Basic training develops candidate flight crews for routine shuttle operations. Recurrent training is related to maintaining flight proficiency especially in critical mission areas during post Phase C/D operations. Additional outputs (of secondary importance) include training in total mission procedures involving interaction between orbiter crew, booster crew, ground mission operations center, manned space flight network, and terminal area controllers.

JUSTIFICATION: The total task aspect of mission simulation presents a complete and continuous mission situation with respect to subsystems operation, crew station environment, and interchange between crews and ground control. This simulation presents a high degree of transfer of training by placing critical vehicle operations within the context of continuous mission events. These events may represent cues required by the flight crews to perform a given task. The crew member must also become acclimated to certain events that are natural to his environment, but unrelated to this task at hand. The mission simulator provides familiarization and training necessary for acclimation. The mission simulator also serves the role of training device for flight control personnel, and is the best means of training flight control personnel in mission procedures in a dynamic environment.

DESCRIPTION: The mission simulator complex consists of both orbiter and booster high fidelity crew stations with out-the-window display systems, instructor-operator station, simulation computer complex and interface with mission control center. The mission simulator complex shall be designed so that each crew station may be used concurrently on separate training activities or linked through the computer complex for training in combined mission operations. A third mode of operation provides for linkage with mission control complex for prelaunch and mission operations training of mission control personnel. A fully redundant hardware data management system with provision for inserting actual flight software

packages shall be an integral part of the booster and orbiter simulators. Use of updated flight software ensures maximum training in mission procedures just prior to flight. The data management system of each vehicle simulator will interface with the simulation complex providing math models of vehicle subsystems, guidance and navigation sensors, LRU's, reference environments. A brief description of each of the major components of the simulation complex follows.

Crew Stations - High fidelity crew stations shall be provided for both the booster and orbiter. All controls, dedicated displays, and video displays mounted on the instrument panels or consoles shall be actual equipment. All nonoperating crew accommodations within the crew station shall be exact replicas of actual hardware. Out-the-window displays shall be provided by virtual image closed-circuit systems covering 180° horizontal and 60° vertical viewing segments. Display generation equipment shall provide realistic views of terrain, cloud cover, near-earth horizons, and for orbiter only, selected star fields and various docking targets. A sound simulation system shall provide aural cues to the flight crew.

Instructor/Operator Station - Interactive on-line terminals shall be provided to enable operators to input selected subsystem malfunctions, monitor effects of the malfunctions and the actions taken. Instructors will monitor subsystem status through addressable video displays accessed through the on-line terminal.

Computers - The mission simulation requires onboard computer hardware and simulation computers. Onboard computer consists of the total redundant data management system that is required to interface the data bus with onboard vehicle subsystems, provide mass memory, and interface data bus to crew station controls and displays. Simulation computer, a general purpose complex, provides simulated vehicle subsystems and vehicle environment simulation for booster and orbiter, total system utility and executive subprograms, and malfunction insertion and monitor subprograms.

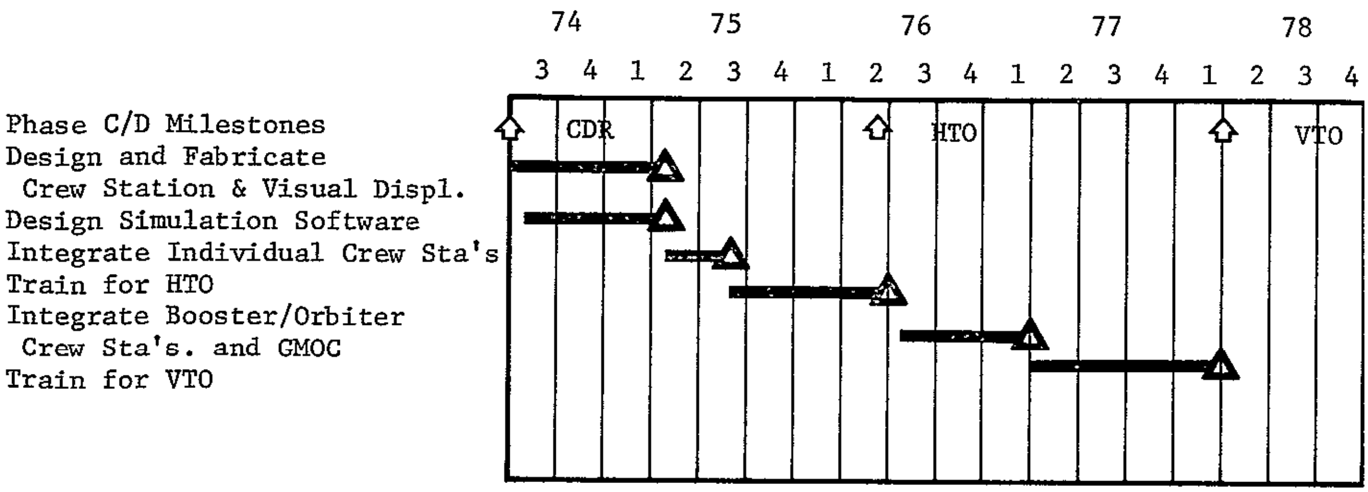
Software - Flight software consists of the complete software package developed for the actual mission. Major elements of the modularized flight software package are executive, data management and bus control, guidance navigation and flight control, utility programs, reconfiguration management, display and control, mass memory, computational subroutines, sensor processing, nonavionics systems, and prelaunch checkout modules. The total software package used for training will be the actual package developed for flight. The simulation software will represent vehicle, environment, simulation timing and control, and utility subprograms.

Simulated vehicle subsystems software represents subsystem operation with sufficient accuracy to provide all cues for high fidelity training situations. The subsystems math models shall be adopted from existing subsystem engineering math models updated to final configuration. Vehicle environment shall consist of a six-degree-of-freedom simulation of vehicle motion in the real world environment. Models used will be adopted from GN&C engineering man-in-the-loop functional simulations. Additional software interface will be required to drive out-the-window display devices. Executive program provides timing reference for real time operation, simulation problem control (problem start, stop, initialization), and simulation system control for synchronous operation of simulation computers, vehicle interfaces, and ground control computers. System utility programs shall provide malfunction insertion and evaluation system software.

FACILITY: The mission simulator consists of the following separate hardware units integrated into one simulation facility:

- o Orbiter vehicle crew station with out-the-window displays
- o Booster vehicle crew station with out-the-window displays
- o Display generation facility
- o Display interface with simulation computer complex
- o GFE data management system - booster and orbiter
- o GFE crew station controls and displays - booster and orbiter
- o Simulation computer complex
- o Simulation computer complex interface with crew stations
- o Instructor/operator station
- o Instructor/operator station interface with simulation computer complex
- o Simulation computer interface with ground operations

SCHEDULE: Design and fabrication of the simulator complex and development of simulation software may start when vehicle hardware has been sufficiently defined. Each vehicle simulator shall be operational prior to horizontal flight test. Combined operation of the integrated facility shall be ready by one year prior to first vertical flight.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Phase C/D Milestones
CDR
HTO
VTO
Design and Fabricate Crew Station & Visual Displ.
Design Simulation Software
Integrate Individual Crew Sta's
Train for HTO
Integrate Booster/Orbiter Crew Sta's. and GMOC
Train for VTO

SRD 1.2.4.1

PAYLOAD DEVICE FAMILIARIZATION AND TRAINING MOCKUPS

OBJECTIVE: The objectives of these mockups are to simulate the various payload handling devices and other special "mission peculiar" devices for familiarization and training of payload handling crew. These mockups shall be used as preliminary familiarization and training devices prior to zero 'g' and neutral buoyancy training.

JUSTIFICATION: Payload device mockups must be made available to verify functional equipment design through use of working full scale models. These mockups shall also provide basic familiarization training in equipment operation and handling prior to basic and recurrent training in zero-'g' or neutral buoyancy environments.

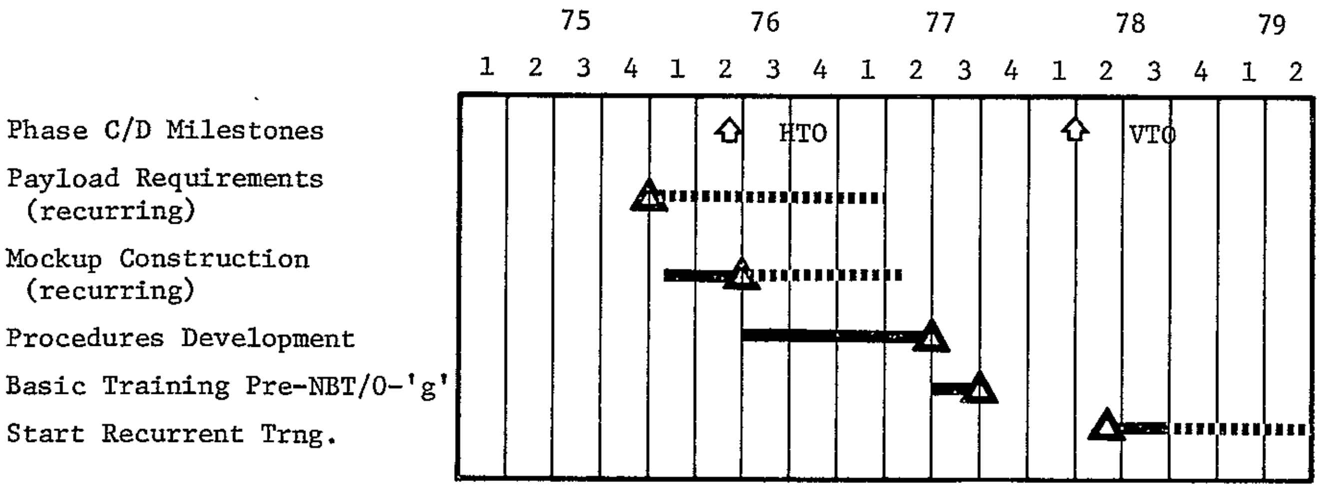
DESCRIPTION: A wide variety of standard payload mockups and "mission peculiar" mockups shall be required, but cannot be defined in detail at this point. In general, mockups will be required to support training of EVA/IVA activities for the various payload classes. These payload classes include:

- Space Station crew-cargo module
- Propellant module
- Satellite placement and retrieval device
- Multiple satellite placement device
- Fixed payloads
- Satellite capture module
- Manned rescue module

Mockups shall be constructed of durable materials to full scale and shall have actual or simulated active devices for familiarization in performance of mission peculiar tasks.

FACILITY: The facility shall consist of a laboratory type area in which the mockups may be located for training activities. The area shall be located at the NASA training facility.

<u>SCHEDULE</u>: Definition of mockup requirements, construction of mockups, and training activity shall begin prior to first vertical flight and shall continue on an "as needed" basis throughout space shuttle operational phase.



SRD 1.2.5.1

GROUND CONTROLLER TRAINING SIMULATION

OBJECTIVE: The objective of this simulation is to provide familiarization and training for ground controllers in ground control console interface with Space Shuttle vehicle during mission operations. Output of this simulation activity will be:

- o Basic familiarization and training in operation of ground controller consoles
- o Recurrent training in ground controller procedures
- o Recurrent training in operational support of Space Shuttle missions
- o Receive contingency training in emergency situations

JUSTIFICATION: The ground crew associated with Ground Mission Operations Center must be trained in operation of the ground control consoles and Space Shuttle mission support operations. The most efficient method of training, which involves simulation of mission operations, is patterned after flight crew training methods. This method enables integrated training in shared facilities utilizing the same training support personnel as for flight crews.

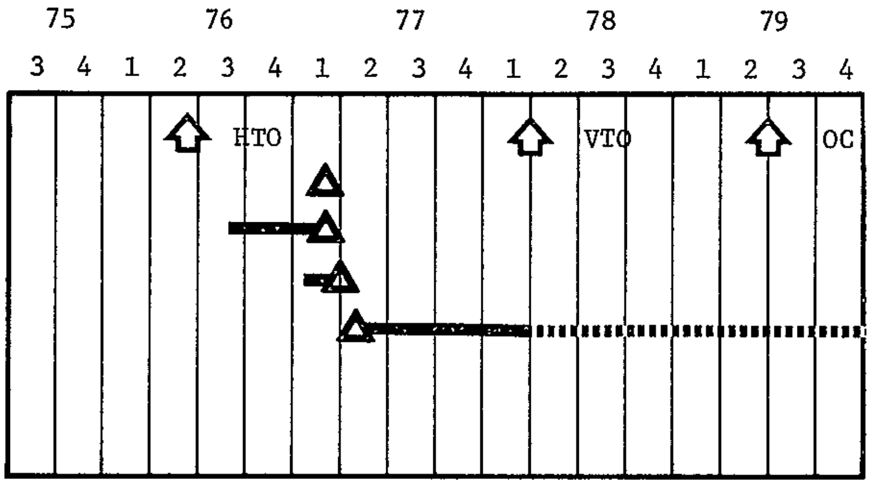
DESCRIPTION: Hardware components of this training simulation activity are actual ground control consoles, mission simulation facility (SRD 1.2.3.1), and all necessary interface equipment. The mission operations training will be conducted through interfacing the real-time mission simulator facility with the actual ground control consoles. In the prelaunch phase this interface would simulate hardline attachment to the vehicle data bus. In post liftoff phases, the interface would simulate the MSFN data link with the vehicle. In either case, real-time data flow between Space Shuttle vehicles and GMOC would be simulated.

Ground station monitoring of simulated mission scenarios will be used to concurrently train ground control personnel on a noninterferring basis during flight crew mission training activities. Support personnel may also be substituted for flight crews to provide separate GMOC controller training in missions operations phased with normal flight crew training activity.

FACILITY: The facility required will consist of actual GMOC hardware interfaced through special interface equipment to the booster/orbiter mission simulator facility.

SCHEDULE: Training simulation equipment and software should be operational by April 1977 to start training twelve months prior to first vertical flight.

Phase C/D Milestones
GMOC Facility Ready
Construct Interface Eqpt.
Integrate and Checkout
Begin Training



SRD 2.1.1.1.1

BOOSTER VARIABLE STABILITY AIRCRAFT FLIGHT SIMULATION

OBJECTIVE: The objective of this task is to provide an in-flight simulation to aid in development of booster vehicle guidance, navigation and control systems for the takeoff, subsonic cruise, terminal approach and landing phases of the mission. Outputs of this simulation will include:

- o Verification of subsonic vehicle stability augmentation system design
- o Evaluation of vehicle handling qualities in varying conditions of wind gusts and turbulence
- o Verification of terminal guidance and navigation procedures for automatic and manual modes
- o Evaluation of GN&C cockpit displays and controls

JUSTIFICATION: Use of a variable stability aircraft for evaluation of subsonic GN&C system characteristics provides an increased level of confidence in system design by providing an extremely close representation to actual system flight characteristics before actual hardware development. This task provides maximum technical penetration of the GN&C design task for subsonic flight regimes.

DESCRIPTION: This simulation task shall be accomplished by using a variable stability aircraft to accurately represent the booster response in subsonic cruise and approach/landing flight conditions. Major hardware components of the variable stability aircraft are the cockpit displays and controls, simulation computer, and terminal landing system avionics.

The cockpit configuration will consist of a single seat with the placement of controls and displays to represent the command pilot's configuration. Visibility out the window will be representative of the booster. General cockpit configuration will be similar to a ground-based GN&C simulator.

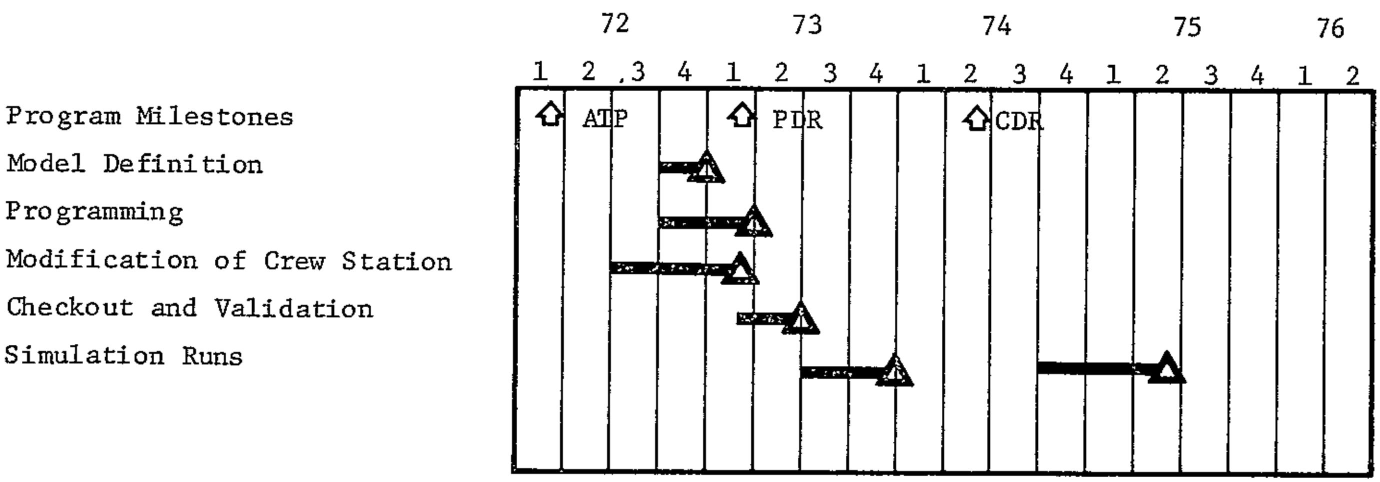
The simulation computer shall mechanize equations of motion of the basic booster vehicle airframe and stability augmentation system loop gains. The computer function during flight will serve to condition surface control system signals causing the test aircraft to respond to pilot or stability augmentation system inputs as the actual booster vehicle would. Guidance and navigation sensor inputs to the flight control system shall also be mechanized by the onboard simulation.

Inputs to the system simulation task shall consist of subsonic vehicle equations of motion derived from aerodynamic data, and guidance, navigation and flight control system design parameters developed through computer simulations, and fixed-base man-in-the-loop simulation activities.

The variable stability aircraft simulator will be utilized in a fashion similar to ground-based simulator facilities by evaluating guidance, navigation and flight control system design at intervals during the development cycle. These intervals will be dependent on major design changes and the resulting requirement for in-flight evaluation.

FACILITY: A variable stability aircraft simulator is required for this task. In order to adequately simulate the booster vehicle, the test vehicle performance capabilities must be beyond the limits of booster vehicle performance for the subsonic flight regime encountered during ferry operations.

SCHEDULE: Use of the variable stability aircraft is required during final stages of the flight control system development, and shall be performed concurrently with GN&C functional simulations of subsonic flight and landing phases.



SRD 2.1.1.1.2

ENVIRONMENTAL SIMULATION OF BOOSTER VEHICLE ASCENT AND REENTRY PHASES

OBJECTIVE: The objective of this simulation is to examine the environmental effects of vibration, "g" loading, and other variables upon crew performance during the ascent and reentry phases of the booster mission. This is of interest for this mission because of the manned configuration and potentially high vibration levels of the combined booster-orbiter vehicle. Outputs of this simulation include:

- o Verify ability of crew to perform required manual operations in normal or abort mode during excessive environmental levels
- o Aid in evaluating methods of suppressing excessive structural vibration/control interaction

JUSTIFICATION: The ability of the flight crew to operate in the shuttle vehicle environment immediately after launch through separation and during high "g" loads in the reentry phase is of concern in meeting total mission objectives. The basic objective, to examine environmental effects upon crew performance, is unique to Space Shuttle and has no precedence from previous space flights. The manned booster is capable of manual flight operations although the majority of the maneuvers are performed in an automatic mode. Booster requirements for launch thrust and staging are critical to the success of the mission and the flight crew must be capable of performing all tasks under the full spectrum of environmental conditions.

DESCRIPTION: Capability of flight crew to perform routine operations and back-up manual control of the vehicle in high vibration/acceleration environments characteristics of launch and reentry phases shall be evaluated. This task shall employ a man-rated centrifuge outfitted with a low fidelity crew station interfaced with a simulation computer. The centrifuge gondola, mounted on a shake-table on the centrifuge rotating member shall contain a half-cockpit mockup representing the booster command pilot's seat. Instrument panel shall contain vehicle situation displays and controls required for normal or emergency manual control during launch/abort phase. Flight control devices shall be installed in the crew station and interfaced with the simulation computers to provide manual backup inputs to the vehicle launch and reentry guidance and control modes.

Crew station accommodations shall include command pilot's seat, portions of the instrument panel and side consoles with correct geometrical relation, and representative crew station lighting. Panel displays and controls required for

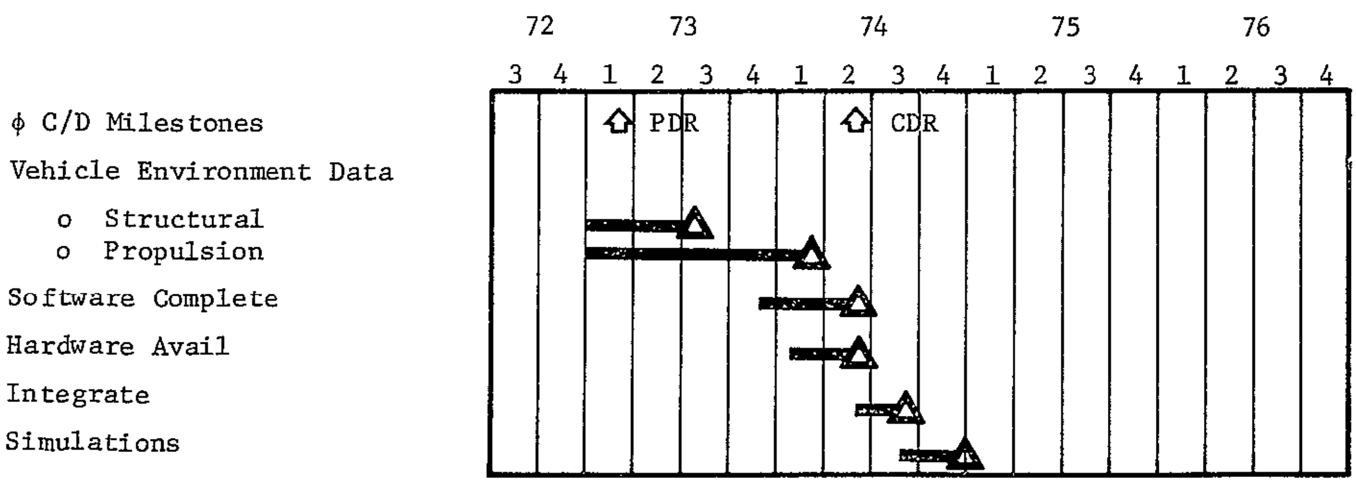
simulation of nominal and emergency situations shall include, dedicated acceleration, rate and attitude instruments, launch sequence and reentry sequence status displays, and abort alarms and displays. Instrumentation shall be reproductions of actual display devices.

Mechanization of math models in the simulation computer shall provide trajectory data and short-period vehicle flight dynamics closing the loop to the centrifuge thereby providing real-time vehicle acceleration components. Forcing functions taken from structural vibration analyses shall be used to drive the gondola shake-table providing simulated longitudinal vehicle dynamics. A vital portion of the simulation shall provide solution for trajectory equations, solutions for fuel sloshing dynamics, statistical data on wind disturbances, and transients associated with vehicles separation.

Combined vehicle dynamics shall be represented through separation in the launch phase. Booster vehicle dynamics shall be represented in the reentry phase. Longitudinal vibration data shall consist of implementing representative vibration levels and frequencies from analyses of the vehicle structural dynamics and applying them statistically to the vehicle model.

FACILITY: The required facility is a man-rated centrifuge with capability of accepting crew station mockups and applying representative longitudinal vibrations during sustained "g" levels. Vehicle dynamics, flight and structural shall be simulated in real time on a medium sized digital computer linked to the centrifuge.

SCHEDULE: The simulation activity will be dependent on when vehicle environmental data is available. Activity shall be concurrent with structural development activity, and man-in-the-loop functional simulations of launch and abort phases.



SRD 2.1.1.2.1

ENVIRONMENTAL SIMULATION OF ORBITER VEHICLE ASCENT AND REENTRY PHASES

OBJECTIVE: The objective of this simulation is to examine the environmental effects of vibration, "g" loading, and other variables upon crew performance during the ascent and reentry phases of the orbiter mission. This is of interest for this mission because of the manned configuration and potentially high vibration levels of the orbiter vehicle. Outputs of this simulation include:

- o Verify ability of crew to perform required manual operations in normal or abort mode during excessive environmental levels
- o Aid in evaluating methods of suppressing excessive structural vibration/control interaction.

JUSTIFICATION: The ability of the flight crew to operate in the environment immediately after separation through orbiter boost phase and during high "g" loads in the reentry phase is of concern in meeting total mission objectives. The basic objective, to examine environmental effects upon crew performance, is unique to Space Shuttle and has no precedence from previous space flights. The manned orbiter is capable of manual flight operations although the majority of the maneuvers are performed in an automatic mode. Orbiter requirements for ascent and insertion are critical to the success of the mission and the flight crew must be capable of performing all tasks under the full spectrum of environmental conditions.

DESCRIPTION: Capability of flight crew to perform routine operations and back-up manual control of the vehicle in high vibration/acceleration environments characteristic of ascent and reentry phases shall be evaluated. This task shall employ a man-rated centrifuge outfitted with a low fidelity crew station interfaced with a simulation computer. The centrifuge gondola, mounted on a shake-table on the centrifuge rotating member shall contain a half-cockpit mockup representing the orbiter command pilot's seat. Instrument panel shall contain vehicle situation displays and controls required for normal or emergency manual control during ascent/abort phase. Flight control devices shall be installed in the crew station and interfaced with the simulation computers to provide manual backup inputs to the vehicle ascent and reentry guidance and control modes.

Crew station accommodations shall include command pilot's seat, portions of the instrument panel and side consoles with correct geometrical relation, and representative crew station lighting. Panel displays and controls required for simulation of nominal and emergency situations shall include dedicated acceleration,

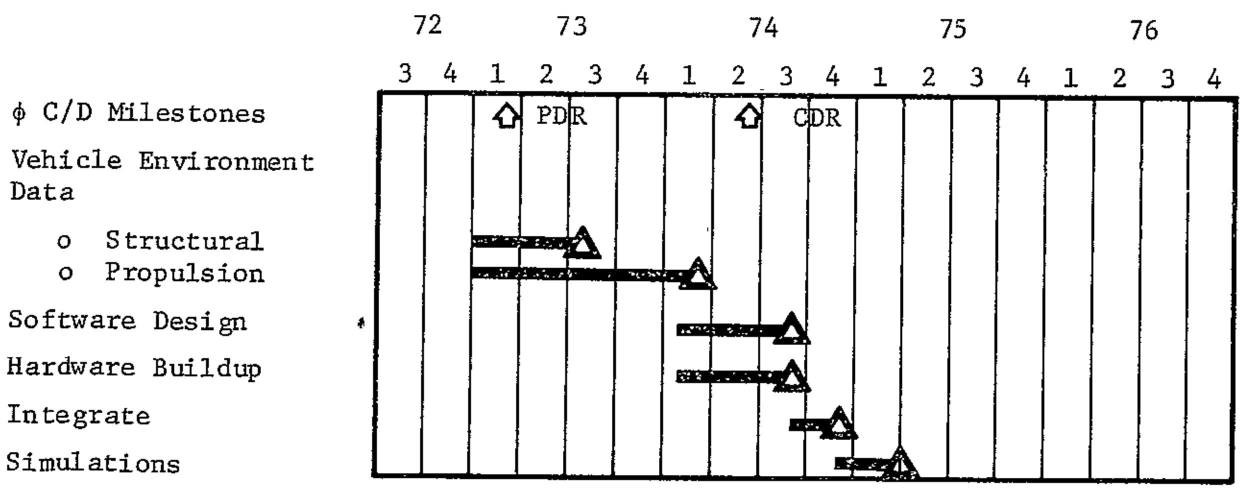
rate and attitude instruments, ascent sequence and reentry sequence status displays, and abort alarms and displays. Instrumentation shall be reproductions of actual display devices.

Mechanization of math models in the simulation computer shall provide trajectory data and short-period vehicle flight dynamics closing the loop to the centrifuge thereby providing real-time vehicle acceleration components. Forcing functions taken from structural vibration analyses shall be used to drive the gondola shake-table providing simulated longitudinal vehicle dynamics.

Orbiter vehicle dynamics shall be represented through the post-separation ascent phase and in the reentry phase. Longitudinal vibration data shall consist of implementing representative vibration levels and frequencies from analyses of the vehicle structural dynamics and applying them statistically to the vehicle model.

FACILITY: The required facility is a man-rated centrifuge with capability of accepting crew station mockups and applying representative longitudinal vibrations during sustained "g" levels. Vehicle dynamics, flight and structural shall be simulated in real time on a medium sized digital computer linked to the centrifuge.

SCHEDULE: The simulation activity will be dependent on when vehicle environmental data is available. Activity shall be concurrent with structural development activity, and man-in-the-loop functional simulations of post-separation launch and abort phases.



SRD 2.1.1.2.2

ORBITER VARIABLE STABILITY AIRCRAFT FLIGHT SIMULATION

OBJECTIVE: The objective of this task is to provide an in-flight simulation to aid in development of orbiter vehicle guidance, navigation and control systems for the takeoff, subsonic cruise, terminal approach and landing phases of the mission. Outputs of this simulation will include:

- Verification of subsonic vehicle stability augmentation system design
- Evaluation of vehicle handling qualities in varying conditions of wind gusts and turbulence
- Verification of terminal guidance and navigation procedures for automatic and manual modes
- Evaluation of GN&C cockpit displays and controls

JUSTIFICATION: Use of a variable stability aircraft for evaluation of subsonic GN&C system characteristics provides an increased level of confidence in system design by providing an extremely close representation to actual system flight characteristics before actual hardware development. This task provides maximum technical penetration of the GN&C design task for subsonic flight regimes.

DESCRIPTION: This simulation task shall be accomplished by using a variable stability aircraft to accurately represent the orbiter response in subsonic cruise and approach/landing flight conditions. Major hardware components of the variable stability aircraft are the cockpit displays and controls, simulation computer, and terminal landing system avionics.

The cockpit configuration will consist of a single seat with the placement of controls and displays to represent the command pilot's configuration. Visibility out the window will be representative of the orbiter. General cockpit configuration will be similar to a ground-based GN&C simulator.

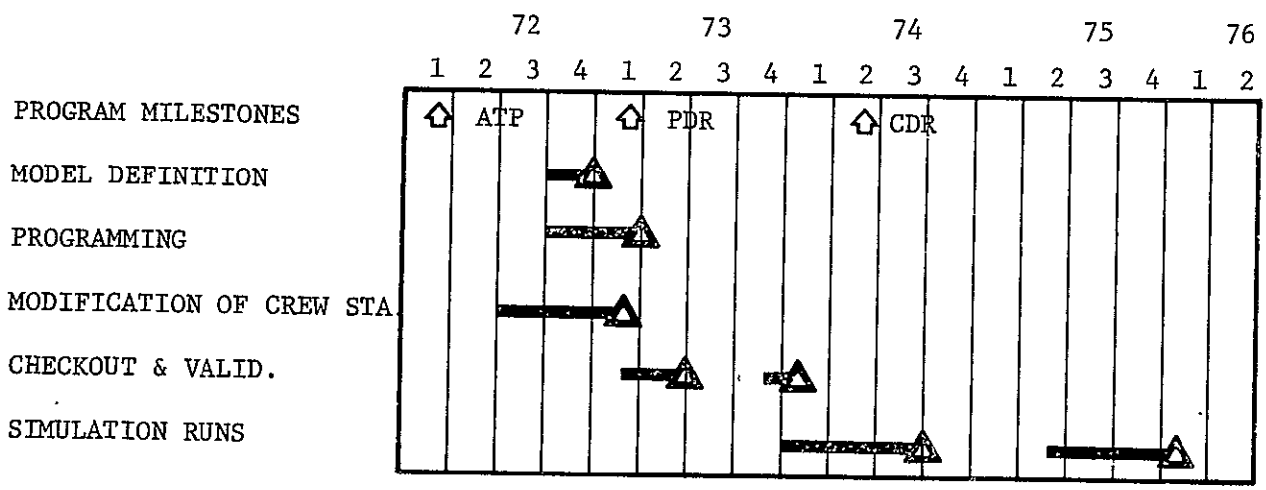
The simulation computer shall mechanize equations of motion of the basic orbiter vehicle airframe and stability augmentation system loop gains. The computer function during flight will serve to condition surface control system signals causing the test aircraft to respond to pilot or stability augmentation system inputs as the actual orbiter vehicle would. Guidance and navigation sensor inputs to the flight control system shall also be mechanized by the onboard simulation.

Inputs to the system simulation task shall consist of subsonic vehicle equations of motion derived from aerodynamic data, and guidance, navigation and flight control system design parameters developed through computer simulations, and fixed-base man-in-the-loop simulation activities.

The variable stability aircraft simulator will be utilized in a fashion similar to ground-based simulator facilities by evaluating guidance, navigation and flight control system design at intervals during the development cycle. These intervals will be dependent on major design changes and the resulting requirement for inflight evaluation.

FACILITY: A variable stability aircraft simulator is required for this task. In order to adequately simulate the orbiter vehicle, the test vehicle performance capabilities must be beyond the limits of orbiter vehicle performance for the subsonic flight regime encountered during ferry operations.

SCHEDULE: Use of the variable stability aircraft is required during final stages of the flight control system development, and shall be performed concurrently with GN&C functional simulations of subsonic flight and landing phases.



SRD 2.2.1.1

HIGH 'G' TRAINING SIMULATION - BOOSTER

OBJECTIVE: The objective of this simulation is to provide basic training in manual control and subsystem management during nominal and emergency situations under high acceleration levels. The launch and reentry phases of booster mission shall be represented in this training effort. Specific outputs of the training effort include:

- o Part-task procedures training for nominal mission phases during high accelerations.
- o Training in recognition and response to emergency situations.
- o Training in manual backup vehicle control during high accelerations.

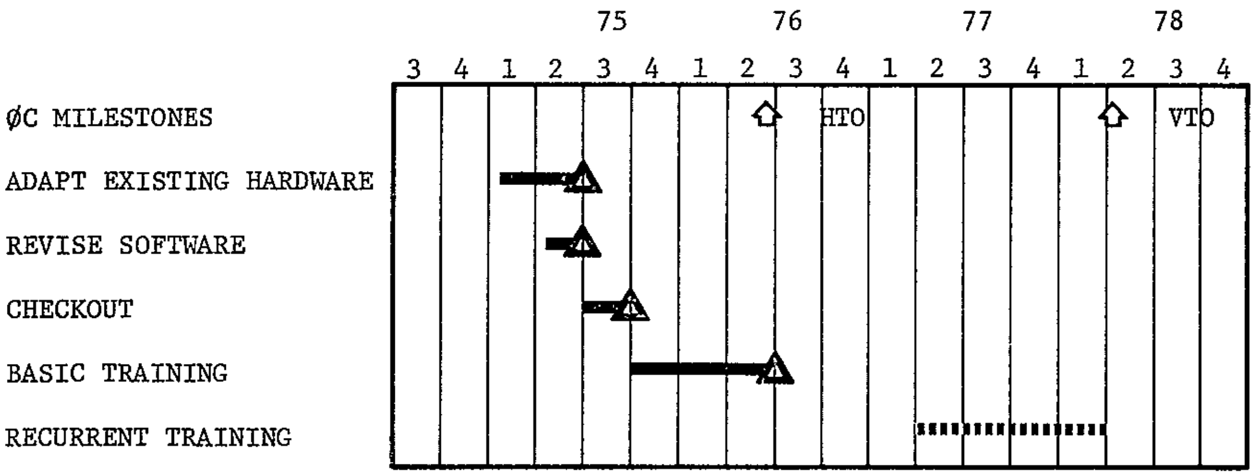
JUSTIFICATION: Critical conditions possibly requiring manual backup control occur at times of relatively high vehicle accelerations. In order to provide optimum transfer of training in nominal and emergency situations, the trainee is placed in a realistic physical environment.

DESCRIPTION: The training task shall employ a man-rated centrifuge outfitted with a low fidelity crew station interfaced with a simulation computer. The centrifuge gondola shall contain a half-cockpit mockup representing the booster command pilot's seat and instrument panel. Instrument panel shall contain vehicle situation displays and controls required for nominal or emergency manual control of vehicle during high accelerations. Primary flight controls devices shall be installed and interfaced with the simulation computer to provide manual inputs to the vehicle math model. Mechanization of math models in the simulation computer shall provide trajectory data and six-degree-of-freedom short-period vehicle dynamics closing the loop to the centrifuge thereby providing real time vehicle acceleration components.

Crew station accommodations shall include production version of the command pilot's seat, portions of the instrument panel and side consoles with correct geometrical relations, and representative crew station lighting. Panel displays and controls required for simulation of nominal and emergency situations shall include dedicated acceleration, rate and attitude instruments, launch sequence and reentry sequence status displays, and abort alarms and displays. Instrumentation shall be reproductions of actual display devices.

FACILITY: The facility shall consist of a man-rated centrifuge with single seat crew station and associated simulation computer capable of simulating the acceleration components during launch for automatic and manned backup of vehicle control.

SCHEDULE: Simulation shall be operable by October 1975, nine months prior to first horizontal flight.



SRD 2.2.1.2

BOOSTER MOTION BASE FLIGHT TRAINING SIMULATION

OBJECTIVE: The objective of this simulation is to provide training in vehicle subsystems management, mission procedures, and GN&C performance for aerodynamic phases of the booster mission. The training task will consist of a continuous simulation of the aerodynamic phase from transition to landing (including total ferry mission operations) utilizing a medium fidelity crew station mounted on five-degree-of-freedom motion-base simulator. Outputs of this simulation will include:

- Basic familiarization and procedures training for aerodynamic phase of booster flight prior to horizontal flight test.
- Recurrent training for skill retention during shuttle program operational phase.
- Basic and recurrent training for ferry mission operations including takeoff, cruise, and landing maneuvers.

JUSTIFICATION: A particularly critical phase of the Shuttle mission takes place at the onset of aerodynamic flight and continues through the landing maneuver. During this phase of flight, the crew receives motion cues and uses them in the adaptive control process of manual flight. Addition of motion cues to the flight training process increases the transfer of training by placing the trainee in a more realistic environment.

DESCRIPTION: The simulator hardware required to perform crew training functions is composed of the following parts: motion base, crew station, visual system, simulation computer, and interface.

The motion base shall provide five-degree-of-freedom motions with nominal travels and accelerations required to reproduce shuttle motion cues encountered in aerodynamic flight regime. It is generally accepted that acceleration is the significant component of vehicle motion that the pilot feels and responds to. Therefore, the motion system shall be designed to impart realistic accelerations at the onset of vehicle motion and then wash out this motion as a compromise with travel limitations of the system. Washout of motion may be considered valid in that an individual tends to adapt to steady state accelerations.

The crew station shall include all active displays and controls required for support of aerodynamic flight training including avionics navaids displays and controls for instrument landing maneuvers. All active instruments will be actual

flight instruments or operating reproductions. Instruments in both sides of the crew station shall be operable. The CRT-type crew/computer interface system shall be operable. Dedicated non-avionics subsystems management displays and controls shall not be operable. A high-fidelity sound system shall be included in the crew station interfacing with the simulation computer to provide sound cues.

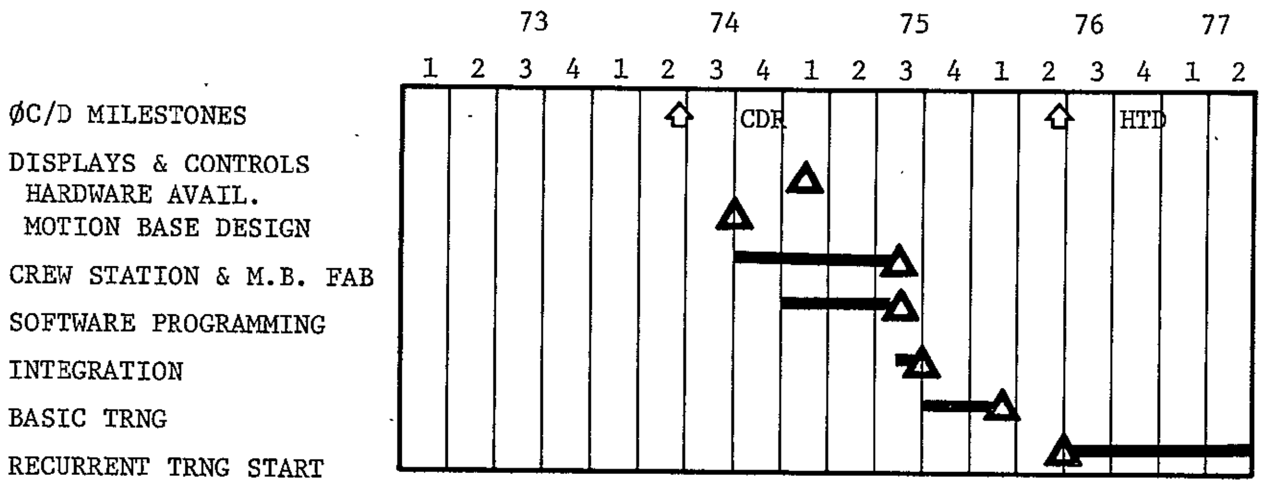
A visual display system shall provide color presentations of out-the-window views depicting terrain features, horizon, cloud cover, and runway detail for the landing phase. The displays shall be implemented as virtual image presentations of closed circuit television scenes. The system shall be capable of continuous visual presentation of the real-world situation throughout aerodynamic flight phase.

The simulation computer shall be a medium scale, general purpose commercial device capable of being programmed in a common scientific language. Interface unit linking the computer and crew station shall be a commercial grade device capable of handling discrete digital signals and processing digital-to-analog and analog-to-digital conversions in synchronism with the computer real-time executive program.

Environment conditions and six-degree-of-freedom equations of motion for aerodynamic flight for the rigid body case shall be adapted from the vehicle software package used in man-in-the-loop functional simulation studies (SRD 1.1.1.1.2). Subsystems simulations shall be derived from engineering simulations and descriptive technical data. Subsystems to be simulated in total are avionics data management, communication and navaids, guidance and navigation, and flight control subsystems. For other nonavionics vehicle subsystems including electrical, hydraulic, propulsion, and ECLS, software will consist only of essential models required to interface with avionics subsystems to provide accurate GN&C simulation of aerodynamic flight, and approach and landing procedures.

FACILITY: A dedicated facility is required consisting of a five-degree-of-freedom motion-base driving a full-sized crew station linked to a medium scale dedicated simulation computer. Out-the-window views shall be implemented by attached closed circuit television displays.

SCHEDULE: Facility shall be complete and operating for basic simulation training nine months prior to horizontal flight test.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ØC/D MILESTONES
CDR
HTD
DISPLAYS & CONTROLS
HARDWARE AVAIL.
MOTION BASE DESIGN
CREW STATION & M.B. FAB
SOFTWARE PROGRAMMING
INTEGRATION
BASIC TRNG
RECURRENT TRNG START

SRD 2.2.1.3

BOOSTER IN-FLIGHT TRAINING SIMULATION

OBJECTIVE: The object of this simulation is to provide familiarization and training in subsonic phase of aerodynamic flight and manual landing procedures. The simulation shall use variable stability aircraft to maximize the flight crew visual and motion cues by simulating booster vehicle critical handling characteristics during the cruise and landing phases. Outputs of the simulation include:

- Familiarization with booster subsonic cruise and landing characteristics prior to horizontal test flight
- Basic training for flight crews entering Shuttle program
- Recurrent training to retain proficiency in booster cruise/landing phases
- Familiarization and training in use of Navaids in terminal navigation and instrument landing

JUSTIFICATION: Subsonic cruise and approach/landing phases of the booster mission involve heavy participation on the part of the crew. The critical landing maneuver may be fully explored prior to actual flight by variable stability aircraft. The variable stability aircraft optimizes preflight training by providing maximum transfer of training through actual visual and physical cues. Recurrent training in landing maneuvers will enable flight crews to retain a high level of proficiency.

DESCRIPTION: This simulation task shall be accomplished by using a variable stability aircraft to accurately represent the booster aerodynamic response in subsonic cruise and approach/landing flight conditions. Major hardware components of the variable stability aircraft are the cockpit controls and displays, simulation computer, and terminal landing system avionics.

The cockpit configuration will consist of a single seat with placement of displays and controls to represent the booster command pilot's configuration. Visibility out-the-window will be representative of the booster. General cockpit configuration will be similar to a low fidelity ground-based GN&C simulator. Active controls and displays will consist of the following:

- o Control Stick
- o Throttles
- o ADI
- o Mach/Airspeed
- o Accelerometer
- o HSI
- o DME Display
- o Rudder Pedals
- o Flaps
- o Altimeter
- o Angle of Attack
- o Rate of Climb
- o VOR/DME & ILS Select
- o VOR/DME & ILS Freq. Select

The on-board simulation computer shall be an analog computer which mechanizes the six-degree-of-freedom booster equations of motion and transfer functions representing vehicle flight control subsystem gains and response characteristics. Equations of motion shall be derived from the equations used in ground based simulations (Ref. SRD 1.1.1.1.2). One complete set of operational Navaids instruments shall be installed to provide navigation and instrument landing system training concurrent with vehicle handling characteristics training in the subsonic cruise and landing regimes. These Navaid systems consisting of commercial airliner-type hardware shall include:

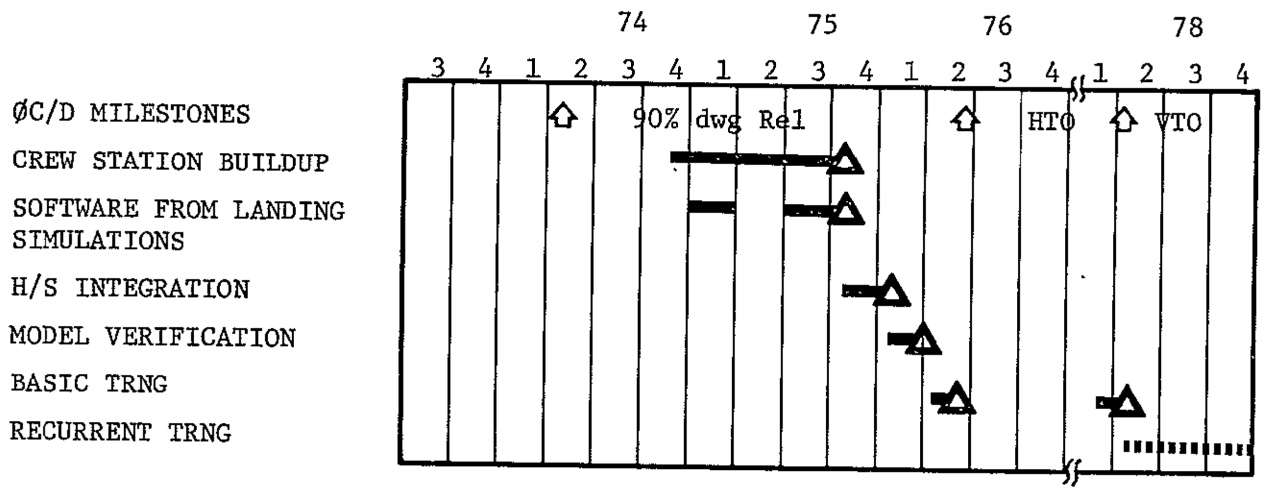
- o VOR
- o ILS
- o DME
- o ATC Transponder
- o Radar Altimeter

Capability of recording parameters such as vehicle attitudes and rates shall be provided to assist in performance evaluation of training subject.

Training program shall consist of flying the aircraft through terminal phase of the booster mission in Manual IFR and VFR modes.

FACILITY: The facility shall consist of one of the existing versions of variable stability aircraft developed to simulate subsonic flying qualities of large aircraft.

SCHEDULE: The equations of motion and instrument system simulation shall be mechanized and checked out by April 1976 with training to commence four months before horizontal flight. During operations phase (post Phase C/D), the training shall take place on a periodic basis to provide recurrent training to prime and backup flight crews.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ØC/D MILESTONES
90% dwg Rel
HTO
VTO
CREW STATION BUILDUP
SOFTWARE FROM LANDING SIMULATIONS
H/S INTEGRATION
MODEL VERIFICATION
BASIC TRNG
RECURRENT TRNG

SRD 2.2.2.1

ZERO GRAVITY FAMILIARIZATION AND TRAINING - ORBITER

OBJECTIVE: The objective of this simulation is to verify crew accommodations and familiarize and train the flight crews in short-term intra-vehicular activity in a zero"g"environment. Specific tasks accomplished by this simulation consist of:

- Develop and qualify short-term IVA procedures and methods
- Provide familiarization and training in critical IVA maneuvers under actual zero gravity conditions
- Evaluate and train in use of crew station hardware and tools
- Evaluate mobility and visibility of pressure suit designs
- Develop and qualify certain EVA procedures and methods related to activities performed external to and near the vehicle

JUSTIFICATION: The Keplerian trajectory flights provide the best possible simulation of zero gravity for familiarization and training in short-term maneuvers. This method is superior in training for performance of tasks related to transportation and handling of bulky and heavy objects in a weightless environment.

DESCRIPTION: This task shall be performed in two phases. The first phase consists of support of crew station design and development and EVA-IVA procedures development. This represents an engineering effort and is done early in Phase C concurrently with crew station design efforts. The second phase represents basic and recurrent training in crew functions critical to zero-"g" environment.

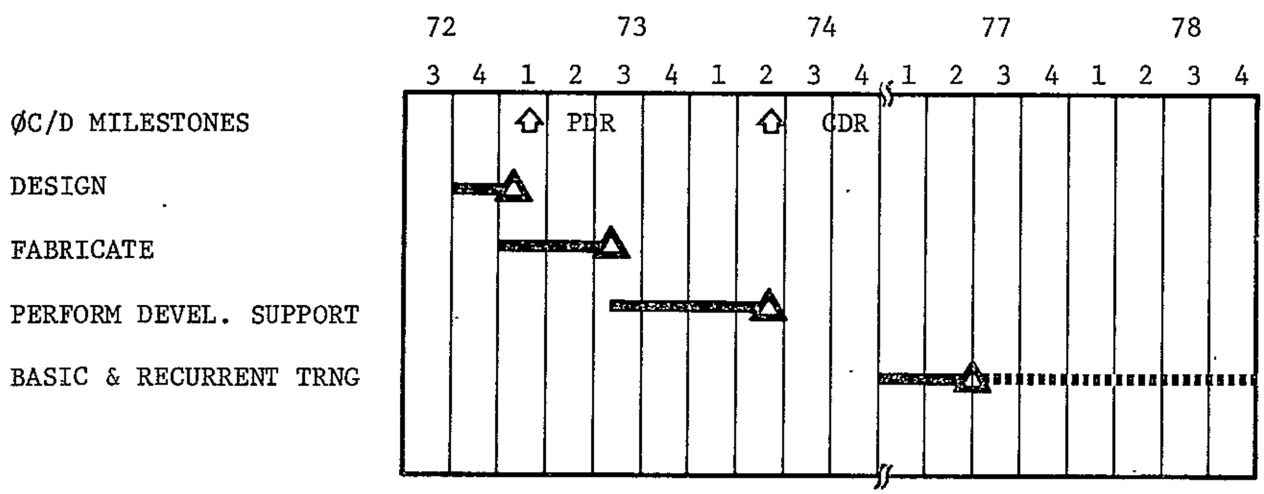
A mockup of the orbiter crew station, airlock, and flexible payload tunnel shall be installed in a KC-135, or equivalent type aircraft. The procedure shall involve flying Keplerian trajectories to develop periods of zero-"g" conditions. Flight crew and engineer test subjects shall perform a variety of intra-vehicle maneuvers and visual-motor tasks required to qualify and train in use of vehicle equipment and mobility procedures.

Long-term tasks may be performed in this environment by breaking them up into a number of short-term subtasks without compromising the training value. Average duration of weightlessness and suitable zero-"g" conditions varies from 20 to 30 seconds.

FACILITY: The facility requirements are a KC-135 aircraft with mockups located in the specially prepared cargo bay area. Due to the KC-135 interior envelope, partial mockups may be required. It may be necessary to perform part of a task

at one mockup segment, move to a second to complete the task. This should not effect training if tasks are properly segmented. Mockup construction must be compatible with aircraft safety (crash loads), mounting points, and lighting systems.

SCHEDULE: The mockup hardware shall be completed and installed in the aircraft by July 1973. Phase I evaluation and development of procedures shall continue through May 1974. Phase II shall start in December 1976 and continue as needed throughout operational phase of Shuttle.



SRD 2.2.2.2

ORBITER NEUTRAL BUOYANCY MOBILITY TRAINING

OBJECTIVE: The objective of this simulation is to train the orbiter crew members in intra-vehicular activities associated with moving through the crew station, airlock and crew access tunnel. The simulation will utilize a mockup of the orbiter crew station, airlock, its hatches, and flex tunnel connecting the airlock and payload module.

JUSTIFICATION: The neutral-buoyancy method of EVA-IVA training allows complete freedom of motion over long periods of simulated zero-"g" environment. This method of training enables conducting long period continuous tasks in a reasonably well simulated environment of weightlessness at a cost less than that of airplane zero-"g" flight. The long term nature of this type of weightless environment is advantageous to procedures development and timeline analysis because of the ease of acquiring multiple run data.

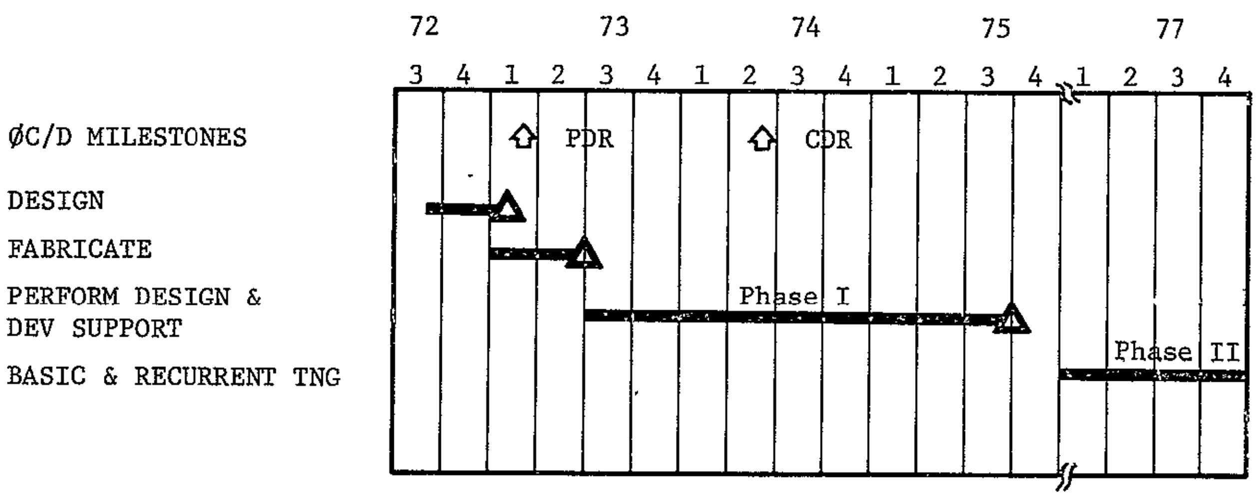
DESCRIPTION: Vehicle crew area mockups required for this training simulation are the crew station, airlock, and positionable flexible crew access tunnel. Operating equipment includes airlock hatches, flex tunnel deployment device, and mission peculiar devices (i.e. experiments, etc.) necessary for training in intra-vehicle activity. All crew mobility and restraint devices will be installed in the crew mockup. Activity related to the neutral buoyancy facility shall be conducted in two phases. The first phase shall involve design support activities. The facility will be used to evaluate crew station design and develop procedures for various mission oriented crew tasks. The second phase, concurrent with flight operations shall involve basic and recurrent training in crew movement within the vehicle and mission oriented tasks.

FACILITY: The basic facility requirement is a large water tank with various crew station mockups required for support of procedures development and training.

The crew station will be immersed in a water tank facility and oriented with the vehicle waterline horizontal. The facility will provide hoisting devices for easy removal of the mockup for inspection, maintenance, and modification. Both pressure suits and standard scuba gear will be used during the course of training. Special precautions shall be taken to insure safe operation of the facility. Major safety provisions include proper procedures, personnel assisting test/training subjects, emergency air supply and emergency exits. Air supply will be derived

from self contained air breathing apparatus of air lines supplied by highly reliable redundant supply systems. The mockup will be designed for emergency egress/ingress in the event of suit or air supply equipment failure. Underwater communications gear will be provided along with recording equipment to assist in training activity. Underwater movie/video equipment and attendant lighting systems will be used.

SCHEDULE: The facility must be completed and available for phase I tasks by July 1973. In order to provide adequate training time, phase II must begin by December 1976.



SRD 2.2.2.3

ORBITER MOTION BASE FLIGHT TRAINING SIMULATION

OBJECTIVE: The objective of this simulation is to provide training in vehicle subsystems management, mission procedures, and GN&C performance for aerodynamic phases of the orbiter mission. The training task will consist of a continuous simulation of the aerodynamic phase from transition to landing (including total ferry mission operations) utilizing a medium fidelity crew station mounted on five-degree-of-freedom motion-base simulator. Outputs of this simulation will include:

- Basic familiarization and procedures training for aerodynamic phase of orbiter flight prior to horizontal flight test.
- Recurrent training for skill retention during Shuttle program operational phase.
- Basic and recurrent training for ferry mission operations including takeoff, cruise, and landing maneuver.

JUSTIFICATION: A particularly critical phase of the Shuttle mission takes place at the onset of aerodynamic flight and continues through the landing maneuver. During this phase of flight, the crew receives motion cues and uses them in the adaptive control process of manual flight. Addition of motion cues to the flight training process increases the transfer of training by placing the trainee in a more realistic environment.

DESCRIPTION: The simulator hardware required to perform crew training functions is composed of the following parts: motion base, crew station, visual system, simulation computer, and interface.

The motion base shall provide five degree-of-freedom motions with nominal travels and accelerations required to reproduce shuttle motion cues encountered in aerodynamic flight regime. It is generally accepted that acceleration is the significant component of vehicle motion that the pilot feels and responds to. Therefore, the motion system shall be designed to impart realistic accelerations at the onset of vehicle motion and then wash out this motion as a compromise with travel limitations of the system. Washout of motion may be considered valid in that an individual tends to adapt to steady state accelerations.

The crew station shall include all active displays and controls required for support of aerodynamic flight training including avionics navaids displays and controls for instrument landing maneuvers. All active instruments will be actual

flight instruments or operating reproductions. Instruments in both sides of the crew station shall be operable. The CRT-type crew/computer interface system shall be operable. Dedicated non-avionics subsystems management displays and controls shall not be operable. A high-fidelity sound system shall be included in the crew station interfacing with the simulation computer to provide sound cues.

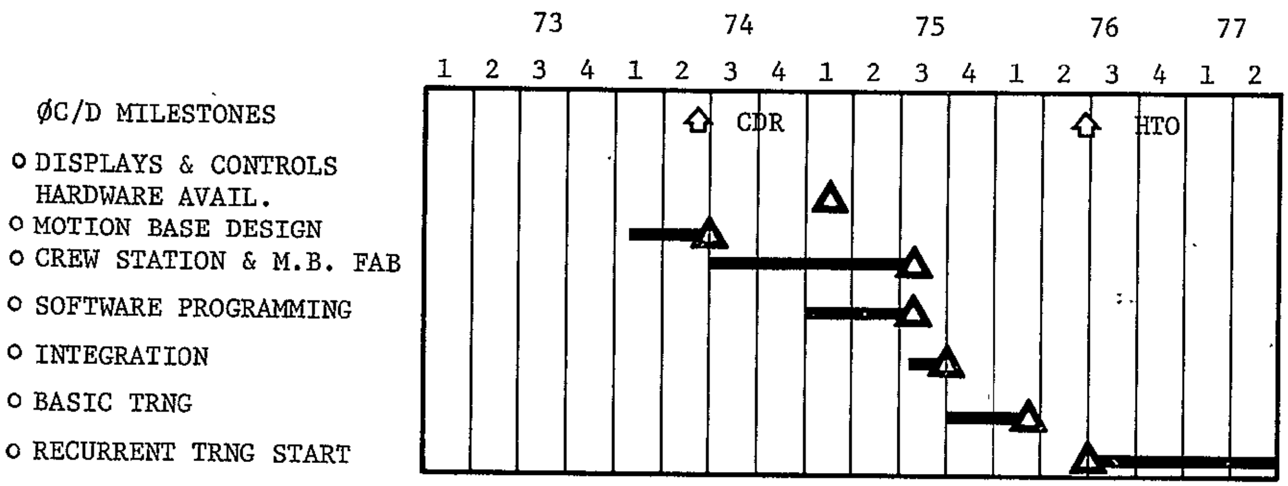
A visual display system shall provide color presentations of out-the-window views depicting terrain features, horizon, cloud cover, and runway detail for the landing phase. The displays shall be implemented as virtual image presentations of closed circuit television scenes. The system shall be capable of continuous visual presentation of the real-world situation throughout aerodynamic flight phase.

The simulation computer shall be a medium scale, general purpose commercial device capable of being programmed in a common scientific language. Interface unit linking the computer and crew station shall be a commercial grade device capable of handling discrete digital signals and processing digital-to-analog and analog-to-digital conversions in synchronism with the computer real-time executive program.

Environmental conditions and six-degree-of-freedom equations of motion for aerodynamic flight for the rigid body case shall be adapted from the vehicle software package used in man-in-the-loop functional simulation studies (SRD 1.1.1.2.2). Subsystems simulations shall be derived from engineering simulations and descriptive technical data. Subsystems to be simulated in total are avionics data management, communication and navaids, guidance and navigation, and flight control subsystems. For other nonavionic vehicle subsystems including electrical, hydraulic, propulsion, and ECLS, software will consist only of essential models required to interface with avionics subsystems to provide accurate GN&C simulation of aerodynamic flight, and approach and landing procedures.

FACILITY: A dedicated facility is required consisting of a five-degree-of-freedom motion-base driving a full-sized crew station linked to a medium scale dedicated simulation computer. Out-the-window views shall be implemented by attached closed circuit television displays.

SCHEDULE: Facility shall be complete and operating for basic simulation training nine months prior to horizontal flight test.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o MOTION BASE DESIGN
o CREW STATION & M.B. FAB
o SOFTWARE PROGRAMMING
o INTEGRATION
o BASIC TRNG
o RECURRENT TRNG START

SRD 2.2.2.4

ORBITER IN-FLIGHT TRAINING SIMULATION

OBJECTIVE: The object of this simulation is to provide familiarization and training in subsonic phase of aerodynamic flight and manual landing procedures. The simulation shall use variable stability aircraft to maximize the flight crew visual and motion cues by simulating orbiter vehicle critical handling characteristics during the cruise and landing phases. Outputs of the simulation include:

- o Familiarization with orbiter subsonic cruise and landing characteristics prior to horizontal test flight
- o Basic training for flight crews entering Shuttle program
- o Recurrent training to retain proficiency in orbiter cruise/landing phases
- o Familiarization and training in use of Navaids in terminal navigation and instrument landing

JUSTIFICATION: Subsonic cruise and approach/landing phases of the orbiter mission involve heavy participation on the part of the crew. The critical landing maneuver may be fully explored prior to actual flight by variable stability aircraft. The variable stability aircraft optimizes preflight training by providing maximum transfer of training through actual visual and physical cues. Recurrent training in landing maneuvers will enable flight crews to retain a high level of proficiency.

DESCRIPTION: This simulation task shall be accomplished by using a variable stability aircraft to accurately represent the orbiter aerodynamic response in subsonic cruise and approach/landing flight conditions. Major hardware components of the variable stability aircraft are the cockpit controls and displays, simulation computer, and terminal landing system avionics.

The cockpit configuration will consist of a single seat with placement of displays and controls to represent the orbiter command pilot's configuration. Visibility out-the-window will be representative of the orbiter. General cockpit configuration will be similar to a low fidelity ground-based GN&C simulator. Active controls and displays will consist of the following:

- o Control Stick
- o Throttles
- o ADI
- o Mach/Airspeed
- o Accelerometer
- o HSI
- o DME Display
- o Rudder Pedals
- o Flaps
- o Altimeter
- o Angle of Attack
- o Rate of Climb
- o VOR/DME & ILS Select
- o VOR/DME & ILS Freq. Select

The on-board simulation computer shall be an analog computer which mechanizes the six-degree-of-freedom orbiter equations of motion and transfer functions representing vehicle flight control subsystem gains and response characteristics. Equations of motion shall be derived from the equations used in ground based simulations (Ref. SRD 1.1.1.2.2). One complete set of operational Navaids instruments shall be installed to provide navigation and instrument landing system training concurrent with vehicle handling characteristics training in the subsonic cruise and landing regimes. These Navaid systems consisting of commercial airliner-type hardware shall include:

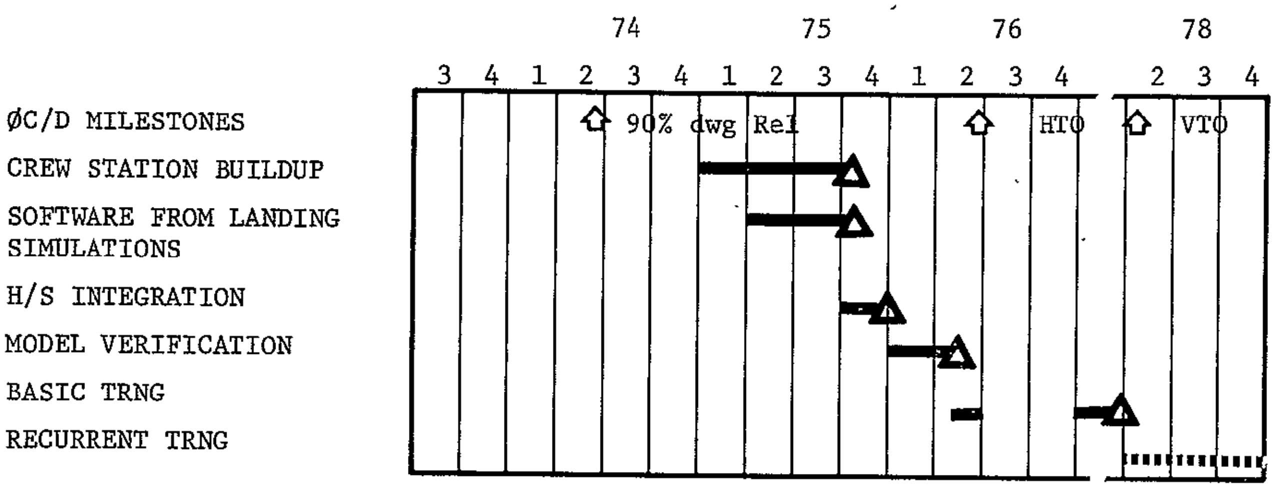
- o VOR
- o ILS
- o DME
- o ATC Transponder
- o Radar Altimeter

Capability of recording parameters such as vehicle attitudes and rates shall be provided to assist in performance evaluation of training subject.

Training program shall consist of flying the aircraft through terminal phase of the orbiter mission in Manual IFR and VFR modes.

FACILITY: The facility shall consist of one of the existing versions of variable stability aircraft developed to simulate subsonic flying qualities of large aircraft.

SCHEDULE: The equations of motion and instrument system simulation shall be mechanized and checked out by April 1976 with training to commence two months before horizontal flight. During operations phase (post phase C/D), the training shall take place on a periodic basis to provide recurrent training to prime and backup flight crews.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ØC/D MILESTONES
90% dwg Rel
HTO
VTO
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SOFTWARE FROM LANDING SIMULATIONS
H/S INTEGRATION
MODEL VERIFICATION
BASIC TRNG
RECURRENT TRNG

SRD 2.2.2.5

FULL-SCALE DOCKING PROCEDURES TRAINING SIMULATION

OBJECTIVE: The objective of this simulation is to provide training in full scale manual translation and docking maneuvers from a position near the target (20 Mtrs.) to actual capture and latch. Output of this training simulation shall include:

- o Qualification of the docking capture and latching mechanism with man in the loop.
- o Development of manual docking techniques and training in contacting and latching with another vehicle.
- o Procedures training in maneuvering near satellites for repair/retrieval/rescue missions
- o Training in use of docking visual aids.

The training activity will involve translation and docking maneuvers with a number of target sizes and shapes.

JUSTIFICATION: The rendezvous and docking maneuver will be critical to mission success in the varied shuttle missions. Crew members must be provided with adequate basic and recurrent training in control of the orbiter vehicle in final stages of the docking maneuver. Variations and improvements in docking procedures, and requirement to maintain skill levels dictate a need for recurrent docking training.

DESCRIPTION: The simulated man-in-the-loop docking maneuver shall be represented by fixed base full-scale orbiter crew station mockup and full scale target mockups mounted on a six degree of freedom motion base with vehicle dynamics mechanized on a simulation computer for closed loop operation. Familiarization and training activity will include docking with various target and vehicle payload configurations which may be used in Shuttle operations. Examples of possible combinations are:

- o Docking orbiter and payload to space station
- o Docking orbiter vehicle to space station
- o Docking orbiter vehicle to another orbiter vehicle
- o Satellite capture using remotely controlled equipment

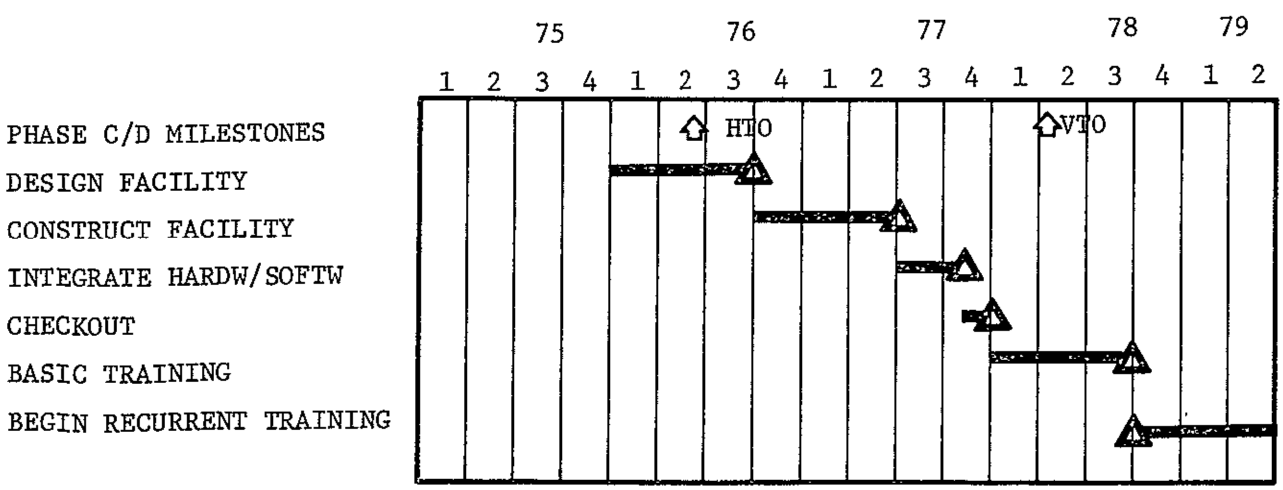
Crew station mockup will represent in a closed cabin, the surroundings, out-the-window visual envelope, and displays and controls required to present a realistic environment to the trainee. The target mockup shall be a full scale

representation of the docking area including docking aids and latching mechanisms. The docking crew station mockup shall be on a fixed base and the target mockup shall have capability for translational and rotational motion with six degrees of freedom. Motion requirements shall be ± 1 radian pitch, roll and yaw angular travel, 25 meters longitudinal (toward target), and 3 meters vertical and lateral travel.

The simulation computer shall be a medium scale digital device capable of being programmed in common scientific language. The computer simulation program shall provide display and controls cues to the docking station instrumentation. Vehicle orbiter equations of motion shall be programmed to give the proper dynamic response to controller inputs. An emergency routine shall be included to prevent contact of vehicle and target if the capture boundary or closing velocity has been exceeded.

FACILITY: Facility required for this simulation is a large-scale translational motion base with six-degrees-of-freedom capable of representing dynamics of motion of the orbiter from approximately 50' to target capture. The target mockup may be modified to represent various target configurations. Target mockups shall be mounted on the motion base to minimize the required mass which must be moved during simulation runs. The motion base and docking crew station shall be located in an enclosed area with ambient light seals to enable training in nighttime docking with supporting external vehicle lighting systems.

SCHEDULE: Simulation setup shall be complete by January 1978 with simulation training being accomplished during 1978, to provide required training prior to rendezvous and docking missions.



SRD 2.2.2.6

HIGH 'G' TRAINING SIMULATION - ORBITER

OBJECTIVE: The objective of this simulation is to provide basic training in manual control and subsystem management during nominal and emergency situations under high acceleration levels. The launch phase of orbiter mission from separation through insertion, and the reentry phase shall be represented in this training effort. Specific outputs of the training effort include:

- Part-task procedures training for nominal mission phases during high accelerations.
- Training in recognition and response to emergency situations.
- Training in manual backup vehicle control during high accelerations.

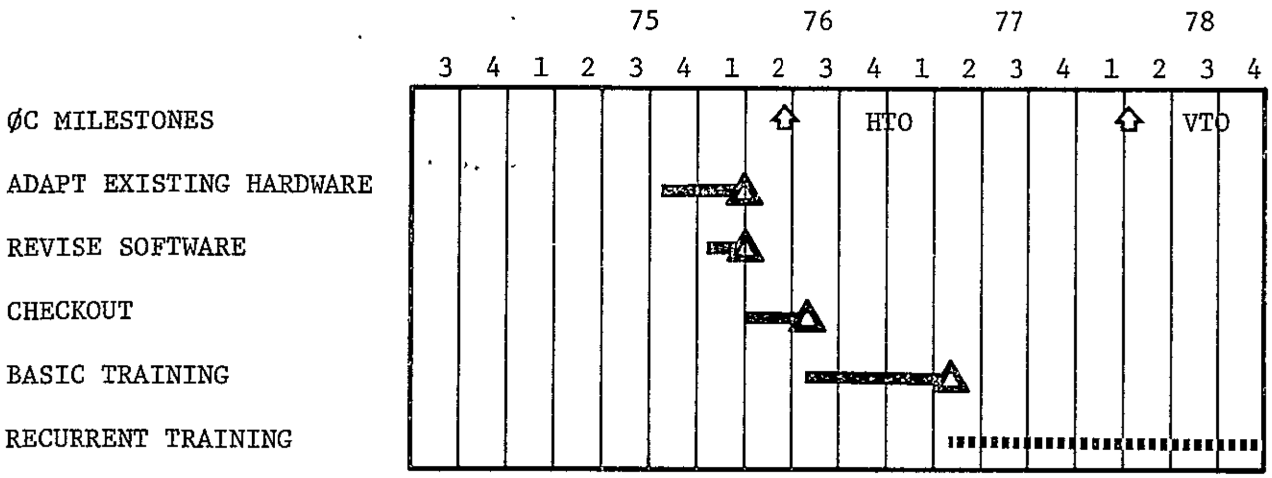
JUSTIFICATION: Critical conditions possibly requiring manual backup control occur at times of relatively high vehicle accelerations. In order to provide optimum transfer of training in nominal and emergency situations, the trainee is placed in a realistic physical environment.

DESCRIPTION: The training task shall employ a man-rated centrifuge outfitted with a low fidelity crew station interfaced with a simulation computer. The centrifuge gondola shall contain a half-cockpit mockup representing the orbiter command pilot's seat and instrument panel. Instrument panel shall contain vehicle situation displays and controls required for nominal or emergency manual control of vehicle during high accelerations. Primary flight controls devices shall be installed and interfaced with the simulation computer to provide manual inputs to the vehicle math model. Mechanization of math models in the simulation computer shall provide trajectory data and six-degree-of-freedom short-period vehicle dynamics closing the loop to the centrifuge thereby providing real time vehicle acceleration components.

Crew station accommodations shall include production version of the command pilot's seat, portions of the instrument panel and side consoles with correct geometrical relations, and representative crew station lighting. Panel displays and controls required for simulation of nominal and emergency situations shall include dedicated acceleration, rate and attitude instruments, launch sequence and reentry sequence status displays, and abort alarms and displays. Instrumentation shall be reproductions of actual display devices.

FACILITY: The facility shall consist of a man-rated centrifuge with single seat crew station and associated simulation computer capable of simulating the acceleration components during launch for automatic and manned backup of vehicle control.

SCHEDULE: Simulation shall be operable by July 1976.



SRD 2.2.3.1

ZERO GRAVITY ACCOMMODATION AND MOBILITY TRAINING - CARGO HANDLER

OBJECTIVE: The objective of this simulation is to verify equipment design, and provide familiarization and training of cargo handlers in various IVA-EVA activities and visual-motor tasks. Outputs of this task include:

- o Develop and qualify EVA-IVA procedures and methods dealing with payload handling activities
- o Provide familiarization and training in critical payload handling activities
- o Evaluate mobility and visibility of pressure suit in performance of payload handling operations
- o Evaluate payload handling device hardware and special equipment

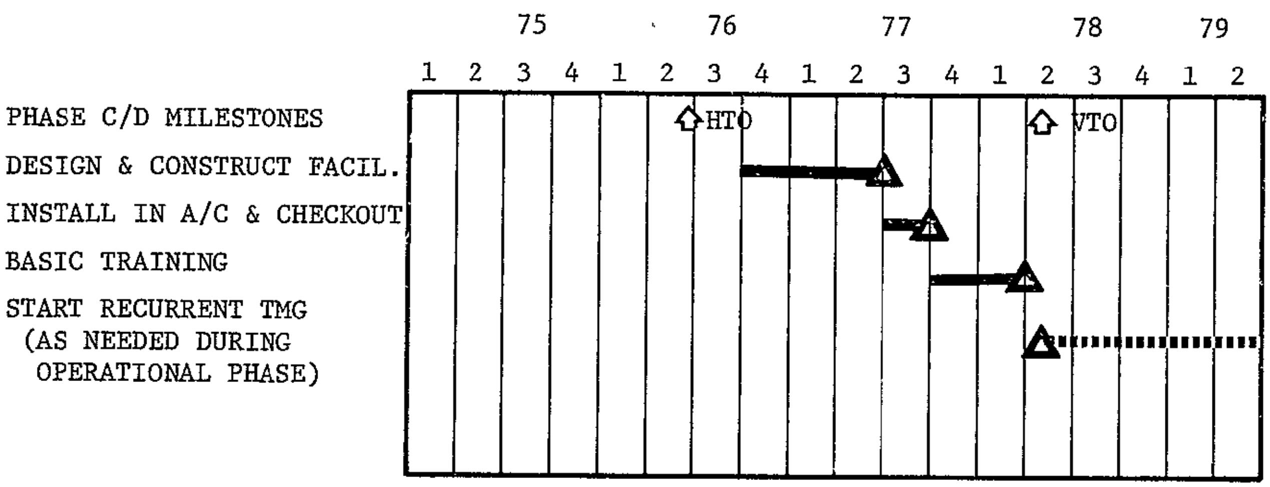
JUSTIFICATION: Keplerian flights provide the best simulation of zero-g environment for training in man-machine tasks involving short term durations. Long term tasks may also be evaluated effectively by breaking up the task into a series of sub-tasks lasting 20-30 seconds. The Keplerian zero-g environment is extremely valuable for training in tasks calling for handling of large masses and volumes and gross body movements that would be hampered by water viscosity in a neutral bouyancy simulation.

DESCRIPTION: High fidelity mockups of active payload equipment shall be installed in a KC-135, or equivalent-type aircraft. The procedure shall involve flying Keplerian trajectories to develop periods of zero-g conditions. Cargo handler and engineer test subjects shall perform a variety of EVA-IVA and visual-motor tasks. Types of training activity will be associated with the following payload classes.

- o Space Station Crew Cargo Module
- o Propellant Delivery Module
- o Satellite placement & retrieval device
- o Multiple satellite placement device
- o Fixed payloads
- o Satellite capture module
- o Manual rescue module

FACILITY: The facility requirements are a KC-135 aircraft with mockups located in the specially prepared cargo bay area. Due to the KC-135 interior envelope, partial mockups may be required. It may be necessary to perform part of a task at one mockup segment and move to a second to complete the task. This should not effect training if tasks are properly segmented. Mockup construction must be compatible with aircraft safety (crash loads), mounting points, and lighting systems.

SCHEDULE: Mockups shall be built and used as required to support cargo handler operations concurrent with space shuttle program activities starting 4th quarter 1977.



SRD 2.2.3.2

NEUTRAL BOUYANCY MOBILITY TRAINING - CARGO HANDLER

OBJECTIVE: The objective of this simulation is to train cargo handler technicians in extra-vehicular activities related to payload, payload deployment, experiments, satellite repair. Engineering objectives include procedures development, and support of hardware design activity.

JUSTIFICATION: Cargo handling operations represent a number of tasks that vary in definition and complexity by mission. Mission-specific training must be accomplished prior to each mission to insure the task conforms with the mission timelines, procedures are correct, and cargo handler is proficient. Of the presently available training means considered (i.e. Keplerian trajectory aircraft, suspension systems, neutral bouyancy) the neutral bouyancy technique is the most cost effective way to provide cargo-handler training. The technique enables continuous long-term evaluation and development of EVA procedures, with a minimum of costly special purpose equipment.

DESCRIPTION: Mockups required for this simulation vary depending upon the payload configuration for the mission peculiar training activity. For most configurations, the mockup will represent the approximate payload dimensions in size. This activity shall be done in two phases. The first phase shall involve support of engineering design and development in evaluating cargo handling hardware and procedures.

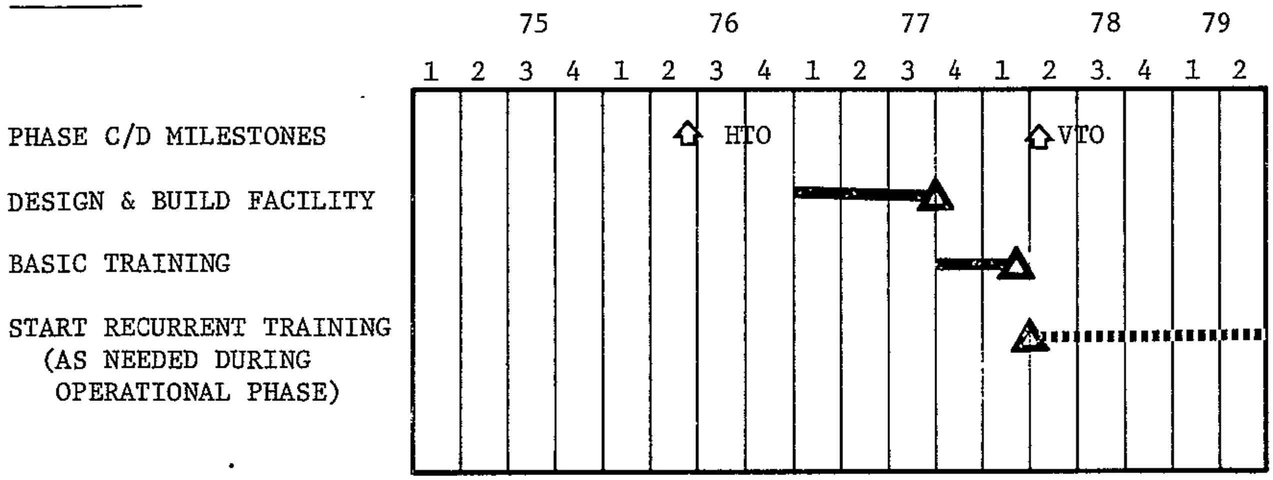
Training activity of phase II shall provide basic and recurrent training in all EVA tasks required to operate the payload equipment in accomplishing any of the following:

Repair and maintenance of satellites, payloads, vehicles, space station
Delivery of propellant to a space station
Delivery of propellant to another vehicle
Satellite placement and retrieval
Multiple satellite deployment
Rescue operations.

FACILITY: The mockups will be immersed in a water tank facility and oriented with the vehicle waterline horizontal. The facility will provide hoisting devices for easy removal of the mockup for modification purposes. Both pressure suits and standard scuba gear will be used during the course of training. Air supply

will be derived from self-contained air breathing apparatus or air lines supplied by highly reliable redundant air supply systems. Mockup will be designed for emergency egress/ingress in the event of suit or air-supply equipment failure. Underwater communications gear will be provided along with recording equipment to assist in training activity. Underwater movie/video equipment and attendant lighting systems will be used to record and critique training activity.

SCHEDULE:



SRD 3.1.1.1

ASCENT ABORT FLYBACK TRAJECTORY SIMULATION - BOOSTER

OBJECTIVE: The purpose of this simulation is to conduct analyses of ascent/abort requirements and capabilities. The outputs from this simulation program will be in the form of:

- Evaluation of abort/separation criteria
- Definition of open loop abort trajectories
- Determination of entry maneuver requirements to achieve landing site
- Definition of flight procedures
- Definition of onboard software requirements

JUSTIFICATION: This all digital ascent abort simulation is required to define abort modes and procedures prior to man-in-the-loop simulation (SRD 1.1.1.1.2) and onboard software specification.

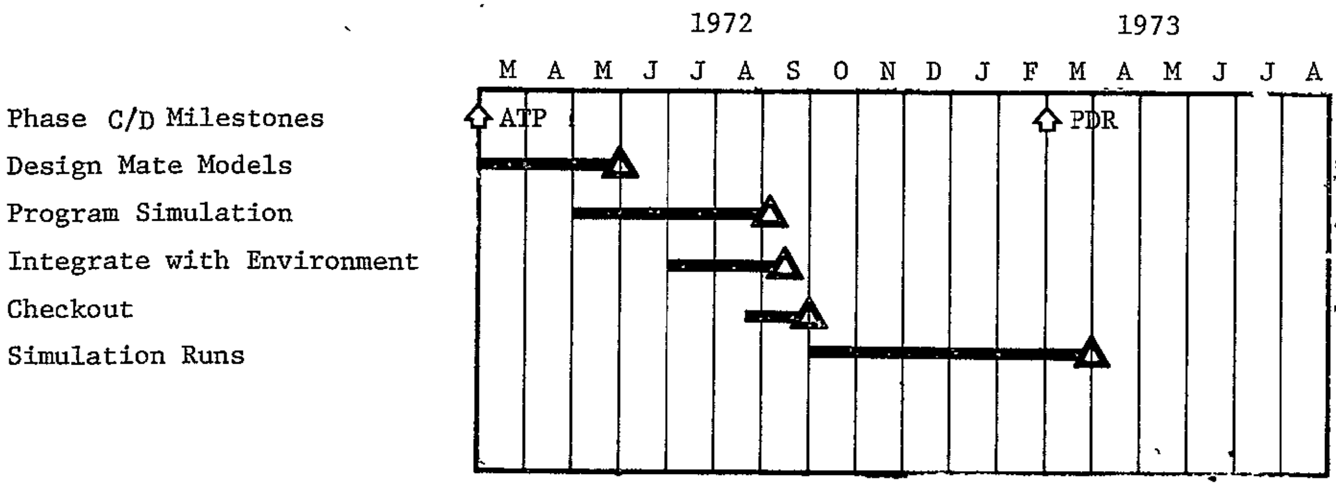
DESCRIPTION: The all digital, six-degree-of-freedom simulations of the ascent abort problem covered by this SRD will encompass booster vehicle ascent abort trajectories for aborts occurring before, during and following booster-orbiter separation. Environmental math models are required for the winds and wind gusts. The vehicle's mass properties, aerodynamics and propulsion are also modeled.

Inputs to this simulation, aside from those required for the above mentioned math models, are definition of constraints (heating, load factor), abort modes and landing sites. Failure probability analysis data will be used to determine cause of aborts and time of aborts, i.e., initial conditions.

The simulations covered by this SRD will be used to rapidly and economically evaluate proposed ascent abort procedures and techniques. Acceptable designs will be further evaluated using man-in-the-loop simulations (SRD 1.1.1.1.2).

FACILITY: Any general purpose digital computer with standard peripherals will be satisfactory for these simulations. The computer shall be capable of being programmed in common scientific language.

SCHEDULE: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PDR
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Program Simulation
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Checkout
Simulation Runs

SRD 3.1.1.2

THEORETICAL TERMINAL TRANSITION SIMULATION - BOOSTER

OBJECTIVE: The purpose of this simulation is to provide a useful tool for analyzing the booster flight characteristics during the transition from hypersonic to supersonic to subsonic phases, from high angle of attack to low angle of attack. Outputs will be:

- o Definition of transition flight envelope
- o Determination of fuel requirements for various dispersion factors
- o Determination of airload and hinge moment requirements

JUSTIFICATION: The transition maneuver is very critical to the successful return of the Booster. Analyses obtained from this simulation could eliminate the expense and excessive time necessary for intermediate flight tests and provide an optimum transition flight profile.

DESCRIPTION: A six-degree-of-freedom computer program will be utilized in this simulation to establish optimum flight characteristics for the Booster mission during the entry and transition phase. Dispersion factors that should be included are:

- o Early and late separation
- o Low mach number
- o Wind gusts

Input parameters that should be included are:

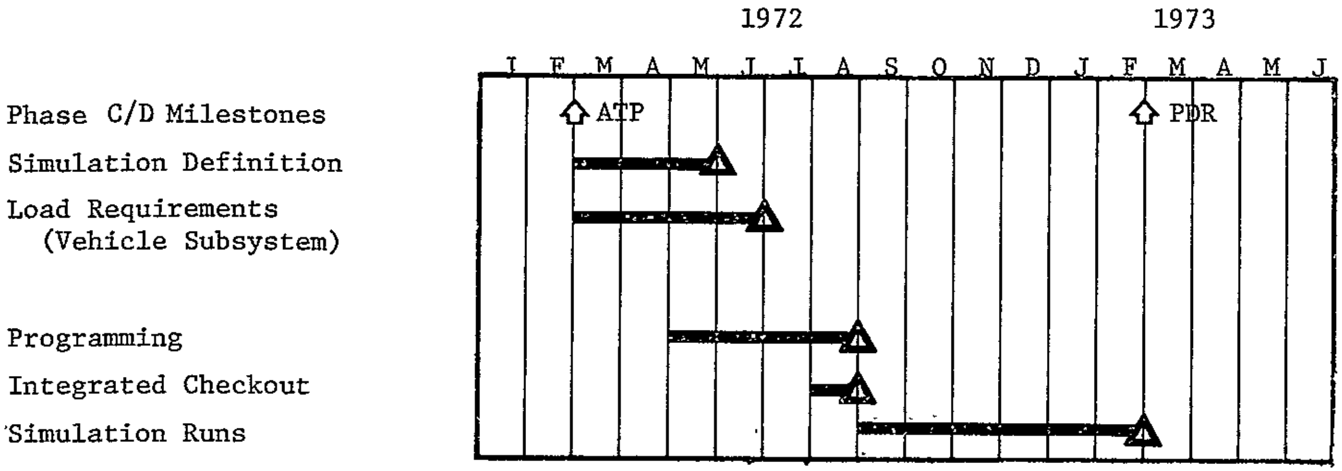
- o Control surface areas
- o Fuel Consumption
- o Vehicle velocities
- o Angle of attack
- o Separation altitude and position

The flight profile of this program should cover analyses of entry maneuvers such as:

- o Reducing of angle of attack to reduce g loads
- o Critical velocities for changes in angle of attack appropriate to supersonic and subsonic flight
- o Banking to decrease cruise to landing site requirements
- o ABES start

FACILITY: A general purpose digital computer with standard peripherals is required for this simulation.

SCHEDULE: This program should be operational prior to the end of Phase C.



SRD 3.1.1.3

THEORETICAL APPROACH, LANDING AND GO AROUND SIMULATION - BOOSTER

OBJECTIVE: The purpose of this simulation is to provide a useful tool for analyzing the booster flight characteristics for maximum range during the approach, landing and go around phase. Outputs from this simulation will include:

- o Establishment of cruise engine thrust requirements
- o Establishment of propellant requirements
- o Curves of trimmed drag and lift versus jet momentum
- o Time line of jet deflection angle and thrust for maximum range

JUSTIFICATION: The jet-flap canard configuration, in which the combination of jet deflection angle and thrust level results in a unique set of trimmed conditions, makes the conventional presentation of drag polar impossible. Combining the variations of pertinent aerodynamic parameters required to maximize the range factor requires the use of a computer program.

DESCRIPTION: This simulation should be performed by a three-degree-of-freedom digital computer program which will include the following parameters as inputs:

- o Weight
- o Angle of attack
- o Jet deflection angle
- o Elevon angle
- o Engine thrust level
- o Speed
- o Altitude
- o CG shift due to fuel transfer during cruise

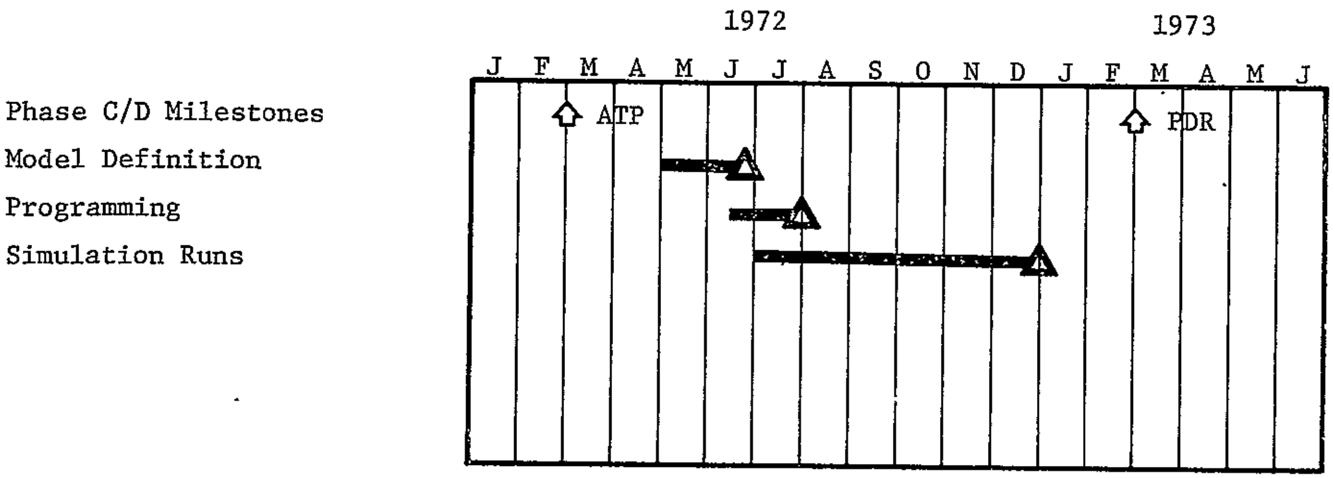
Other parameters that should be varied in determining the maximum range factor are:

- o Engine combinations
- o Wind velocities
- o Bank angle
- o Side slip angle

Wind tunnel data, analytical methods and transport aircraft experience can be used to estimate the aerodynamic characteristics of the booster for powered cruise back portion of the mission.

FACILITY: A large scientific digital computer with standard peripherals will be required for this simulation.

SCHEDULE: This simulation should be run early in Phase C to provide inputs to engine design, fuel feed system design, and jet-flap control system developments.



SRD 3.1.1.4

FLIGHT TEST SUPPORT SIMULATION - BOOSTER

OBJECTIVE: The purpose of this simulation is to establish flight test capabilities and procedures through analysis of off-nominal trajectories for booster ascent and entry phases. Outputs of this simulation include:

- o Flight test envelopes
- o Abort envelopes
- o Test mission profiles

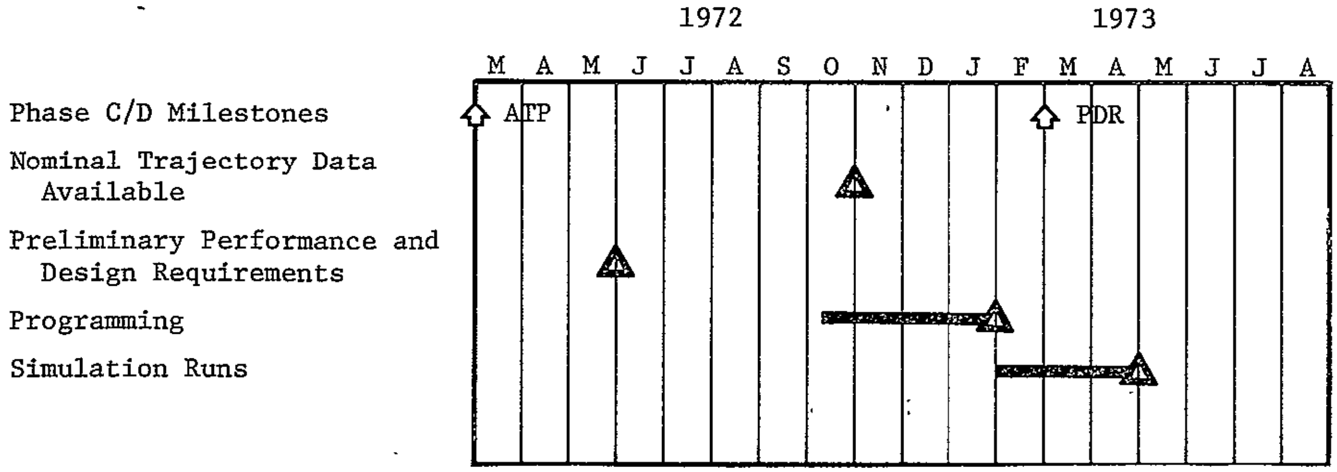
JUSTIFICATION: Computer trajectory simulation of planned flight test profiles are used to verify that off-nominal flight conditions will meet flight test objectives and that phased buildup from less critical to more than critical flight conditions will coincide with program development goals and maintain proper safety factors.

DESCRIPTION: The basis of these trajectory simulations are point-mass trajectory programs and generalized aircraft programs derived from SRD's 3.1.1.2, 3.1.1.3 and 3.1.3.2. These programs coupled with booster aero characteristics, propulsion characteristics, mass properties shall be used to evaluate planned flight test trajectories. These trajectory analyses will verify that structural loads, entry heating, and attitude control limits are within orbiter design limits. Additional inputs required are:

- o Test philosophy
- o Test location and landing site
- o Vehicle constraints (e.g., heating, load factor)

FACILITY: A general purpose digital computer with standard peripherals is required for this simulation. The program shall be capable of being programmed in common scientific language.

SCHEDULE: This simulation shall be run after completion of nominal trajectory simulations and vehicle structural constraints are defined. This simulation shall be run well in advance of flight test activity for planning purposes.



SRD 3.1.1.5.

FERRY MISSION SIMULATIONS - BOOSTER

OBJECTIVE: The objective of this simulation is to define the balanced field length requirements, nose wheel lift-off characteristics, and takeoff, cruise and landing performance and procedures for the booster vehicle. Outputs from these simulations will include:

- Evaluation of ferry mode capabilities
- Definition of ferry mode flight procedures
- Establishment of ferry mode operational constraints (e.g., balanced field length, flight envelopes, ferry range capability and landing field distance)

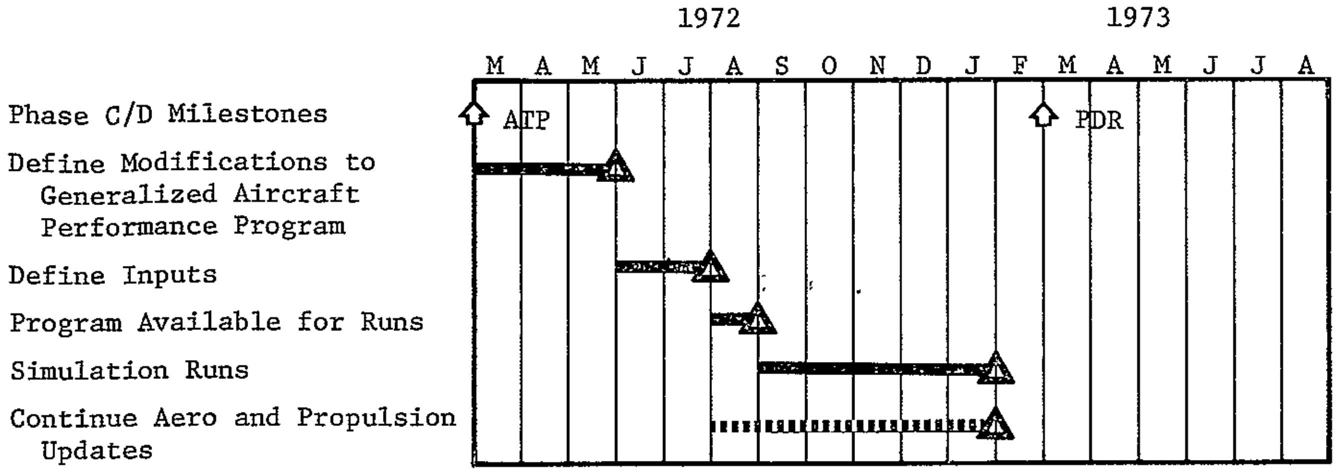
JUSTIFICATION: These simulations are required early in vehicle development phase to demonstrate capability of the booster vehicle to perform ferry mission, thereby satisfying design requirements.

DESCRIPTION: These all-digital, generalized aircraft performance simulations will be used to determine the ferry mode capabilities and operational constraints for the booster vehicle. Output data concerning performance, such as balanced field length and ferry range capability, will be useful especially in mission planning and analysis. Environment models required for these simulation programs are gravitational acceleration, atmosphere, winds and wind gusts. Vehicle related models are required to describe the structure with aerodynamic surfaces and controls, aerodynamic response characteristics, mass properties, propulsion, and autopilot.

Input data for these simulations include initial conditions for vehicle, mass model and propulsion characteristics, take-off runway characteristics, maneuver schedule or flight plan, and terminal runway characteristics.

FACILITY: A large scale digital computer with standard peripherals is required. The computer shall be capable of being programmed in common scientific language.

SCHEDULE: Simulation shall be done early in Phase C/D to demonstrate capability of vehicle design and to provide inputs for development of man-in-loop techniques and procedures for ferry mission.



SRD 3.1.2.1

ASCENT TRAJECTORY SIMULATIONS - ORBITER

OBJECTIVE: The purpose of this simulation is to provide nominal and dispersed open-loop ascent trajectories. Outputs from this simulation activity will include:

- o Evaluation of optimum performance
- o Definition of system flight characteristics
- o Ascent trajectory time histories
- o Data for mission analysis and mission profiles
- o Initial condition data for abort studies
- o Definition of flight procedures

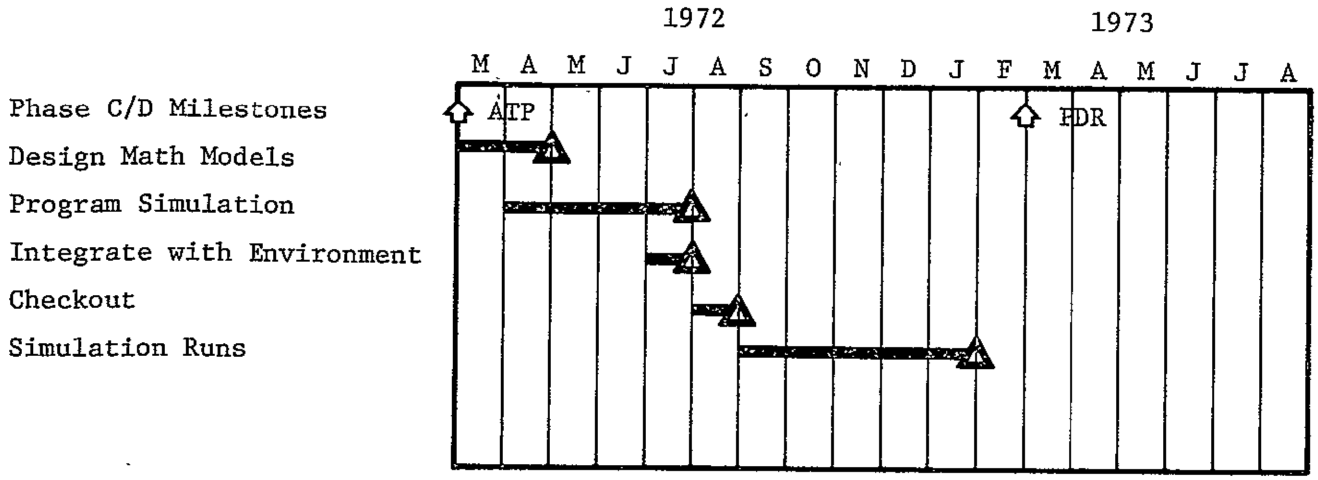
JUSTIFICATION: This simulation activity is required to determine operational envelopes with respect to constraints (e.g., q limit and load limits).

DESCRIPTION: The all-digital three degree-of-freedom point mass simulation program covered by this SRD will be used to define nominal and dispersed ascent trajectories for the orbiter from separation through insertion.

Input data will consist of nominal vehicle mass properties and uncertainties, nominal aerodynamics characteristics and uncertainties, nominal engine thrust and variations, nominal staging velocity and uncertainties, nominal staging coast time and uncertainties, and desired injection conditions. In addition all constraints must be input (e.g., axial load factor and angle of attack/dynamic pressure limits).

FACILITY: Any general purpose digital computer with standard peripherals will be satisfactory for execution of this simulation. The computer shall be capable of being programmed in common scientific language.

SCHEDULE: This simulation shall be run prior to ascent phase GN&C simulations in order to provide ascent trajectory data.



SRD 3.1.2.2

ASCENT ABORT FLYBACK TRAJECTORY SIMULATION - ORBITER

OBJECTIVE: The purpose of this simulation is to conduct six-degree-of-freedom analysis of ascent/abort requirements and capabilities. The outputs from this simulation program will be in the form of:

- Evaluation of abort/separation criteria
- Definition of open loop abort trajectories
- Determination of entry maneuver requirements to achieve landing site
- Definition of flight procedures
- Definition of onboard software requirements

JUSTIFICATION: This all-digital ascent abort simulation is required to define abort modes and procedures prior to man-in-the-loop simulation (SRD 1.1.1.2.1) and onboard software specification.

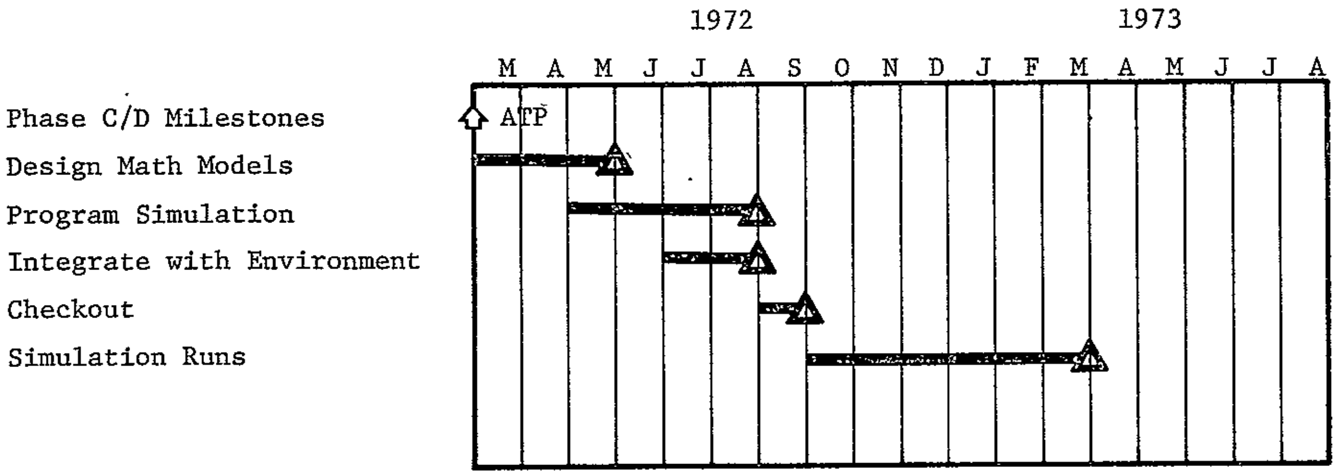
DESCRIPTION: The all-digital, six-degree-of-freedom simulations of the ascent abort problem covered by this SRD will encompass orbiter vehicle ascent abort trajectories for aborts occurring before, during and following booster-orbiter separation. Environmental math models are required for the winds and wind gusts. The vehicle's mass properties, aerodynamics and propulsion are also modeled.

Inputs to this simulation, aside from those required for the above mentioned math models, are definition of constraints (heating, load factor), abort modes and landing sites. Failure probability analysis data will be used to determine cause of aborts and time of aborts (i.e., initial conditions).

The simulations covered by this SRD will be used to rapidly and economically evaluate proposed ascent abort procedures and techniques. Acceptable designs will be further evaluated using man-in-the-loop simulations (SRD 1.1.1.2.2).

FACILITY: Any general purpose digital computer with standard peripherals will be satisfactory for these simulations. The computer shall be capable of being programmed in common scientific language

<u>SCHEDULE</u>: This simulation shall be run prior to abort phase of man-in-loop GN&C simulations.



SRD 3.1.2.3

REENTRY TRAJECTORY SIMULATION - ORBITER

OBJECTIVE: The purpose of this simulation is to establish nominal and maximum maneuvering reentry trajectories considering heating, heating rate, angles of attack and loading constraints. Outputs from this simulation will be:

- o Definition of open-loop, reentry footprint
- o Determination of orbiter vehicle flight characteristics
- o Data for mission analysis and mission profiles

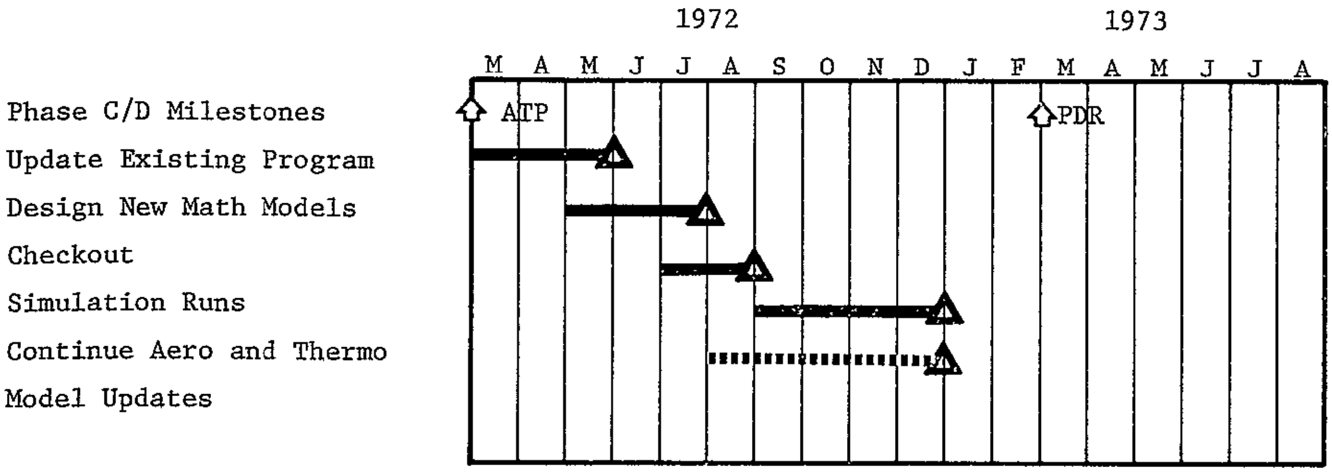
JUSTIFICATION: This simulation will be used to verify the adequacy of the orbiter's ranging capabilities for attainment of landing sites without using airbreathing engines.

DESCRIPTION: The all digital point-mass reentry trajectory simulation covered by this SRD will be used to define the reentry footprint landing capabilities for nominal and dispersed conditions. The environmental models required are: gravitational potential for an aspherical earth; rotating earth; atmosphere as a function of altitude; winds and wind gusts.

Input data will be required to specify nominal and off nominal conditions at atmosphere encounter (i.e., at an altitude of 122 km). Simulations will be performed to fully define the angle of attack and bank angle modulation necessary to achieve maximum ranging capability within constraints. These maximum maneuvering boundaries and man-in-the-loop closed loop performance simulations described in SRDs 1.1.1.2.1 and 1.1.1.2.2.

FACILITY: Any general purpose digital computer with standard peripherals will be satisfactory for this simulation. The computer shall be capable of being programmed in a common scientific language.

SCHEDULE: These simulations shall be done sufficiently early to enable inputs to be made to the man-in-the-loop simulations of reentry phase. The activity under this SRD shall continue as aerodynamics and thermodynamics models are updated.



SRD 3.1.2.4

THEORETICAL TERMINAL TRANSITION SIMULATION - ORBITER

OBJECTIVE: The purpose of this simulation is to establish the vehicles dynamic response characteristics during the supersonic angle of attack transition. Outputs from this simulation will be:

- o Definition of transition flight modes (i.e., envelope)
- o Definition of maneuver schedule
- o Establishment of pilot flight procedures
- o Establishment of fuel requirements
- o Establishment of airload and hinge moment requirements

JUSTIFICATION: This simulation is required to define the angle of attack transition maneuver schedule.

DESCRIPTION: The all-digital, six-degree-of-freedom simulation program covered by this SRD will be used to define the supersonic angle of attack transition. The blending of the reaction jet and aerodynamic controls will be defined and reaction jet fuel requirements specified.

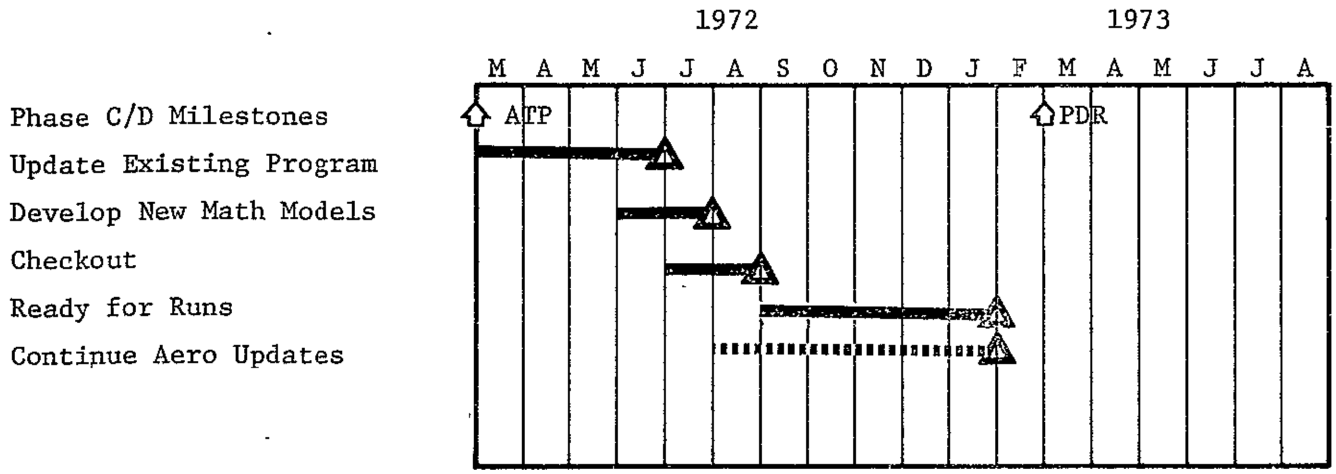
The environment required for this simulation will include the math models for a gravitational potential for an aspherical earth, atmosphere as a function of altitude, and appropriate wind profiles. The systems models required are:

- o Vehicle mass properties as a function of consumables
- o Vehicle and control surfaces aerodynamic characteristics
- o Attitude control propulsion system
- o Autopilot control law for transition

Inputs to this simulation program include the trisonic aerodynamic characteristics and initial condition data, vehicle position and attitude from entry trajectory simulations.

FACILITY: Any general purpose digital computer with standard peripherals will be satisfactory for this simulation.

SCHEDULE: This simulation must be done early to provide inputs to man-in-loop simulation activity. This simulation activity will be continued as aerodynamic data is updated.



SRD 3.1.2.5

THEORETICAL APPROACH, LANDING AND GO-AROUND SIMULATION - ORBITER

OBJECTIVE: Establish the orbiter flight characteristics for the high energy approach, landing and abort go-around regimes. Outputs from this simulation will include:

- o Definition of approach flight mode envelope and procedures
- o Definition of go-around criteria
- o Establishment of abort pullup and go-around procedures and fuel requirements
- o Definition of landing performance, powered and unpowered

JUSTIFICATION: This simulation provides verification of concepts and demonstrates capability to satisfy mission requirements by making use of computer techniques.

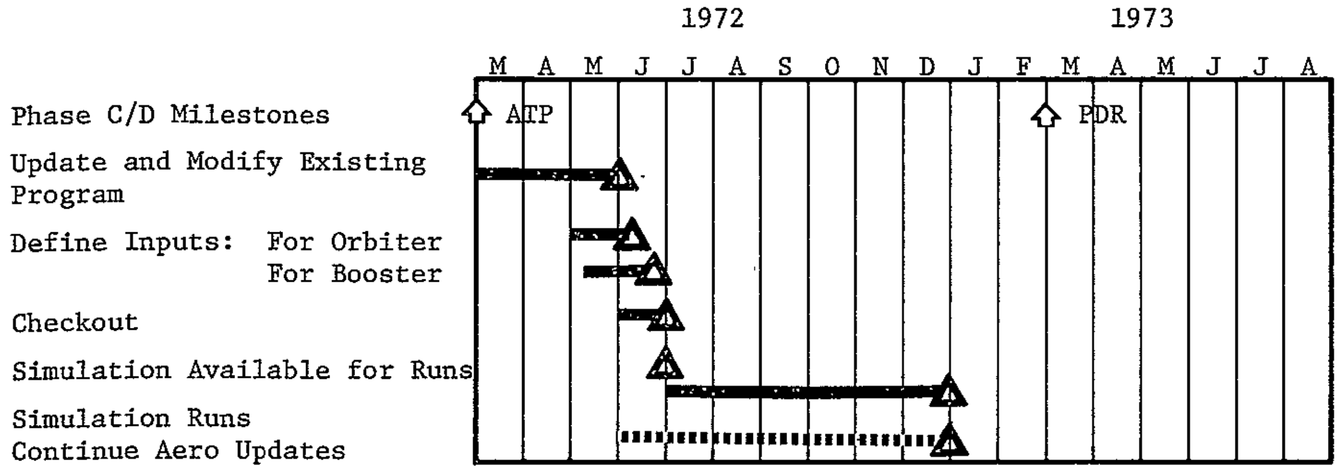
DESCRIPTION: This all digital, three degrees-of-freedom generalized aircraft performance program will be used to evaluate approach, landing and go-around concepts. The environment for this simulation includes math models for the gravitational acceleration, atmosphere, winds, wind gusts and airport approach and landing aids. The vehicle's system math models required are:

- o Mass properties
- o Aerodynamics, subsonic and ground effects
- o Airbreathing engine system

Inputs to the simulation are required for the initial conditions, go-around criteria and guidance laws.

FACILITY: Any general purpose digital computer with standard peripherals will be satisfactory for the simulation.

SCHEDULE: Acceptable performance must be verified prior to finalizing the vehicle's design, and prior to completion of man-in-the-loop landing simulations.



SRD 3.1.2.6

THEORETICAL FERRY MISSION SIMULATION - ORBITER

OBJECTIVE: Define the balanced field length requirements, nose wheel lift-off characteristics, take-off, climb, cruise and landing performance and flight procedures for the booster and orbiter vehicles. Outputs from these simulations will include:

- o Evaluation of ferry mode capabilities
- o Definition of ferry mode flight procedures
- o Establishment of ferry mode operational constraints, e.g. balanced field length, flight envelopes, ferry range capability, and landing field distance

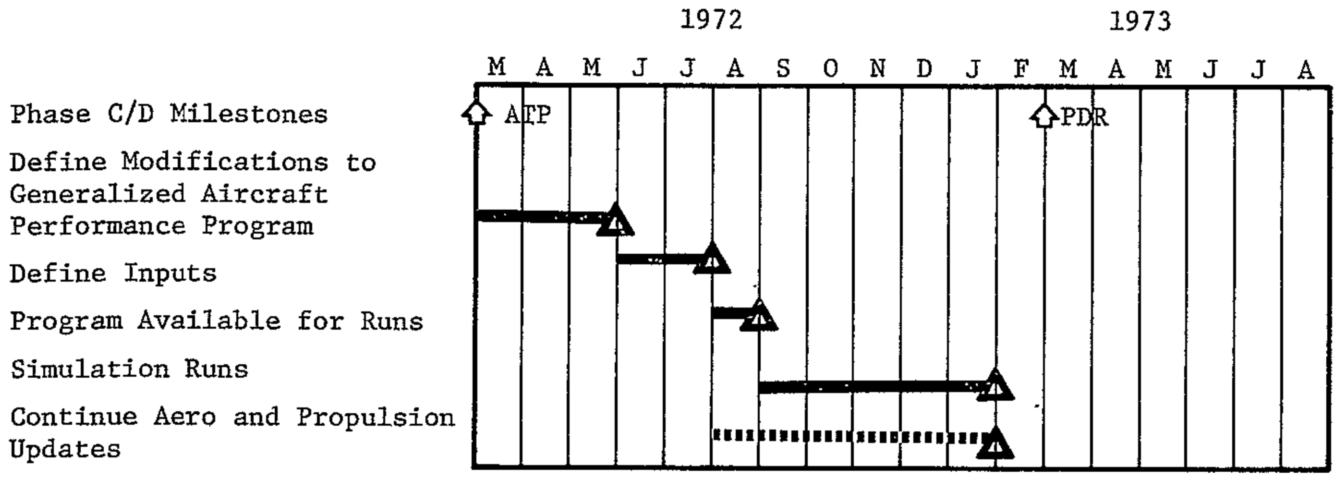
JUSTIFICATION: Evaluation of ferry mission capabilities is necessary to demonstrate capability to satisfy mission requirements. The most cost effective means is through computer simulation.

DESCRIPTION: These all-digital, generalized aircraft performance simulations will be used to determine the ferry mode capabilities and operational constraints for the orbiter vehicle. Output data concerning performance, such as balanced field length and ferry range capability, will be useful especially in mission planning and analysis. Environment models required for these simulation programs are gravitational acceleration, atmosphere, winds and wind gusts. Vehicle related models are required to describe the structure with aerodynamic surfaces and controls, aerodynamic response characteristics, mass properties, propulsion, and autopilot.

Input data for these simulations includes initial conditions for vehicle (Mass model and propulsion characteristics) and take-off runway, maneuver schedule or flight plan, and terminal runway.

FACILITY: Any general purpose digital computer with standard peripherals will be satisfactory for these simulations.

SCHEDULE: Simulation shall be done early in Phase C/D to demonstrate capability of vehicle design and to provide inputs for development of man-in-loop techniques and procedures for ferry mission.



SRD 3.1.2.7

FLIGHT TEST SUPPORT SIMULATION - ORBITER

OBJECTIVE: The purpose of this simulation is to establish flight test capabilities and procedures through analysis of off-nominal trajectories for orbiter ascent and entry phases. Outputs of this simulation include:

- o Flight test envelopes
- o Abort envelopes
- o Test mission profiles

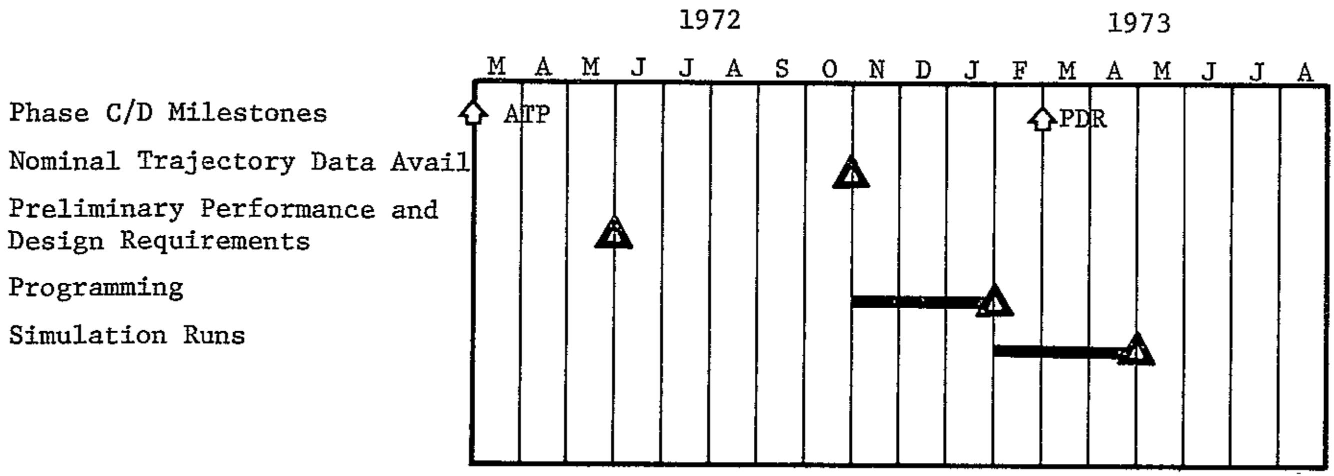
JUSTIFICATION: Computer trajectory simulation of planned flight test profiles are used to verify that off-nominal flight conditions will meet flight test objectives and that phased buildup from less critical to more than critical flight conditions will coincide with program development goals and maintain proper safety factors.

DESCRIPTION: The basis of these trajectory simulations are point-mass trajectory programs and generalized aircraft programs derived from SRD's 3.1.2.1, 3.1.2.3, 3.1.2.4 and 3.1.2.5. These programs coupled with orbiter aero characteristics, propulsion characteristics, mass properties shall be used to evaluate planned flight test trajectories. These trajectory analyses will verify that structural loads, entry heating, and attitude control limits are within orbiter design limits. Additional inputs required are:

- o Test philosophy
- o Test location and landing site
- o Vehicle constraints (e.g., heating, load factor)

FACILITY: A general purpose digital computer with standard peripherals is required for this simulation. The program shall be capable of being programmed in common scientific language.

SCHEDULE: This simulation shall be run after completion of nominal trajectory simulations and vehicle structural constraints are defined. Simulation shall be run well in advance of flight test activity for planning purposes.



SRD 3.1.3.1

BOOSTER/ORBITER SEPARATION SIMULATION

OBJECTIVE: This simulation will provide a tool for evaluating performance characteristics of booster and orbiter separation under environments existing at each time point along ascent trajectory. Outputs should include:

- o Development of proper time-to-go algorithms
- o Evaluation of orbiter plume impingement effects on booster dynamics
- o Evaluation of separation transients on control system

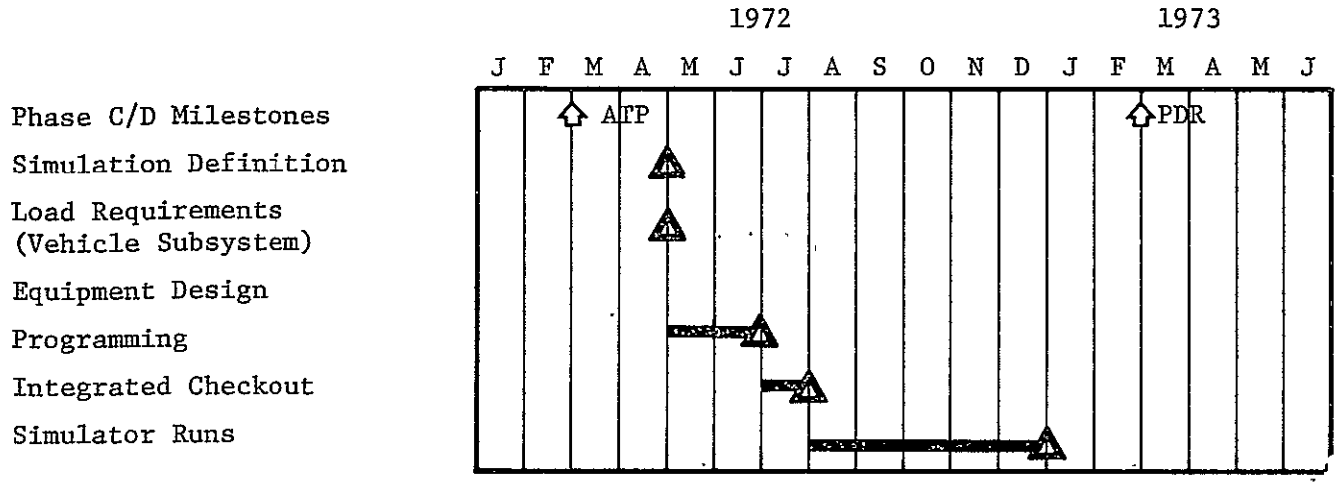
JUSTIFICATION: The uniqueness of the two vehicle space shuttle design creates an analysis problem in dynamic imbalance, plume impingement and crosscoupling not previously encountered. Computer analysis is the only practical way to accomplish this task at an early stage of design.

DESCRIPTION: This will be a two-body, six-degree-of-freedom simulation. The effects on the control system including inherently long time lag between guidance signals and development of correctional control forces must be considered in this analysis along with:

- o Recontact
- o Dynamic pressure
- o Attitude rates
- o Interference aerodynamics
- o Orbiter plume impingement on booster dynamics
- o Delay loops (in transmission)
- o Program running rate
- o Thrust delay
- o CG shift at time of separation
- o Ascent propellant dynamics

FACILITY: A general purpose digital computer with standard peripherals is required for this simulation. The computer should be capable of handling the environment subprogram in conjunction with this program.

SCHEDULE: The program should be operational early in Phase C.



SRD 3.1.3.2

ASCENT TRAJECTORY SIMULATIONS - BOOSTER

OBJECTIVE: The purpose of this simulation is to determine an optimal ascent trajectory by establishing basic performance capability and determing design criteria which will allow development of ascent guidance-targeting techniques. It will assure compatibility of orbiter, booster and aerodynamic configurations through ascent trajectory analyses. Outputs from this simulation should include:

- Initial structural design requirements
- Initial aerodynamic thermal loading
- Initial control design requirements
- Initial hydraulics design requirements
- Payload capability
- Altitude versus velocity characteristics
- Angle of attack versus dynamic pressure
- Profile of design trajectories for:
  Maximum acceleration
  Maximum dynamic pressure
  Maximum aerodynamic heating

JUSTIFICATION: Trajectory characteristics are tied in closely with many vehicle design problems. Because of the autonomous nature of the shuttle system, existing boost vehicle guidance technology must be expanded to allow the taking of last minute weight and mission changes, reshaping the ascent trajectory, and reporting on available performance margins. To effectively perform an analysis as sophisticated as this requires the use of a computer program.

DESCRIPTION: This will be a digital three-degree-of-freedom simulation. Programs such as required for this simulation are in general use throughout the industry and can be utilized with modifications to develop design trajectories.

Some of the outputs from this simulation which will be utilized as inputs to other simulations are as follows:

OUTPUT	INPUT TO
o Payload capability and aerodynamic thermal loading	o Entry trajectory heating and aerodynamic loads
o Altitude/velocity	o Ascent heating
o Angle of attack and dynamic pressure history	o Structural load analysis
o End of boost conditions and heating and aerodynamic loading conditions	o Entry trajectory
o Entry trajectory data	o Ascent trajectory

The program should include the following:

- o Weight breakdown model using tabular sizing data
- o Lift-off simulated by controlling inertial attitudes until tilt maneuver is completed
- o Aerodynamic model for atmospheric trajectory should include:
  Simple lift-drag polar as function of mach
  Effects of assymmetric lift
- o Propulsion simulation should accommodate liquid and solid engines
- o Total vehicle thrust constrained axial acceleration to prescribed limits

Some of the vehicle control modes that should be considered are:

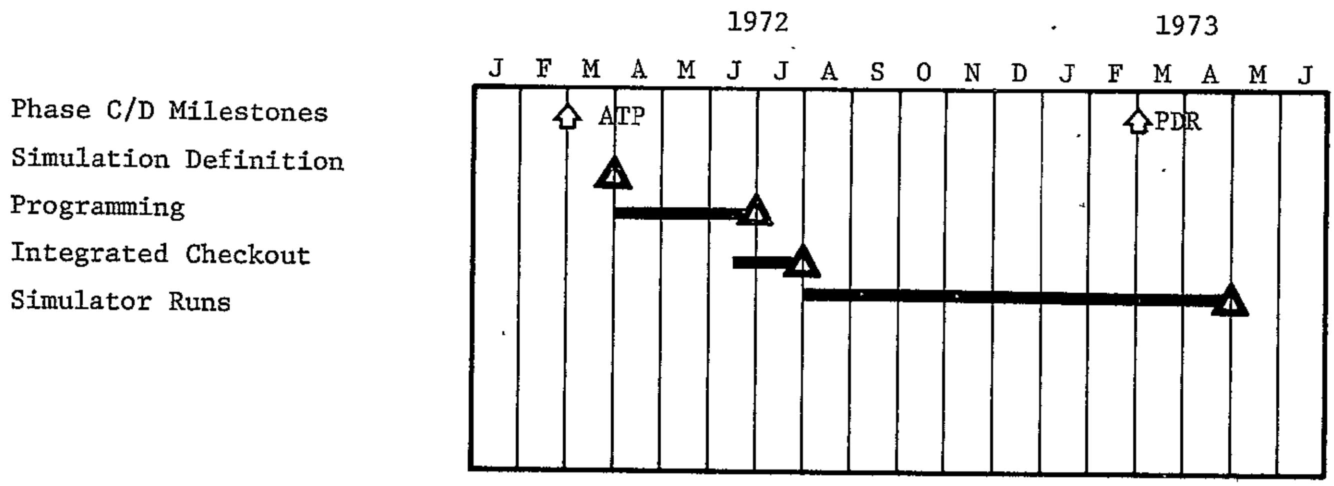
- o Gravity turn
- o Zero lift mode
- o Zero bank angle
- o Vertical rise
- o Horizontal takeoff
- o Fixed azimuth with optional pitch angle of attack
- o Preprogrammed control history

During ascent inequality constraints should be imposed on:

- o Dynamic pressure
- o Axial load factor
- o Normal load factor
- o Total heat load
- o Angle of attack limits

FACILITY: The facility required for this simulation is a scientific digital computer which can be programmed in standard scientific language.

SCHEDULE: The program should be operational early in Phase C and will be rerun as design and mission profile changes occur.



SRD 3.1.3.3

ENGINE OUT TRAJECTORY SIMULATION - BOOSTER

OBJECTIVE: This simulation will be used to establish trajectory limitations with various engine out combinations. The outputs should include the following:

- o Vehicle dynamic response presented in the form of:
  Profiles of angle of attack
  Dynamic pressure
  Normal acceleration
  Angular acceleration
  Engine deflection
- o Determination if control of vehicle can be maintained
- o Determination if the structural loads are within safe levels
- o Determination if desired trajectory can be achieved

JUSTIFICATION: A computer simulation is the most efficient and safest way to determine the effects of engine out within the time and expense limitations of the program.

DESCRIPTION: This should be a six-degree-of-freedom computer simulation. The math model for this simulation will include the effects of engine out on the other engine's performance such as:

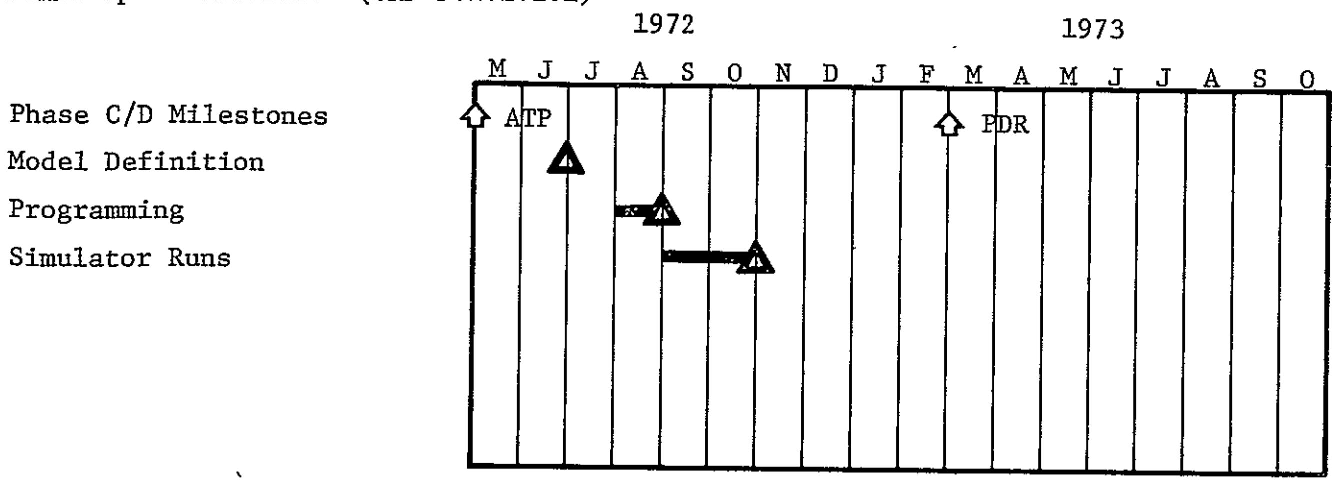
- o Power level
- o Gimballing
- o Throttling requirements

The effect of loss of lift should be considered with respect to controls. Dispersions in selected parameters should be inputs. These should include:

- o Wind disturbances
- o Altitude error
- o Center of gravity
- o Center of pressure
- o Angle of attack gains
- o Individual engine thrust
- o Total thrust for most critical engine out trajectories

FACILITY: A scientifically oriented digital computer with standard peripheral equipment can be utilized to run this simulation.

SCHEDULE: This simulation should be run early in design phase, after thrust build up simulation. (SRD 5.1.1.1.1)



SRD 3.2.1.1

DETERMINATION OF BOOSTER VIBRATION SPECTRA

OBJECTIVE: This simulation will determine the Booster structural response to acoustic and boundary layer noise for the purposes of

- o establishing equipment vibration test requirements,
- o determining crew vibration environments,
- o determining vibration-induced structural loads on airframe and external panel and support structure.

JUSTIFICATION: Early vibration information is required for design of all spacecraft equipment and subsystems. Early iterations of spacecraft structural design must include vibration loading, especially in the area of external thermal protection system (TPS) panels. Sometimes scaled and modified data from other similar vehicles is used for design purposes. Simulation is required because this type of data is not available for Shuttle due to the uniqueness of its configuration. The cost of this simulation will be more than offset by the savings in equipment and structural weight made possible by the accurate prediction of vibrational stresses.

DESCRIPTION: This simulation will use a finite-element model of the Booster structure plus math models of lift-off rocket noise, transonic and supersonic boundary layer noise, as well as cruise jet engine noise, including ground engine run-up. Response will then be obtained by means of math models of the structural responses to these acoustic pressures.

The rocket and jet engine noise models including spatial distribution will be constructed from experimental data. Aerodynamic fluctuating pressure data will be obtained from wind tunnel tests.

The distinct computer runs required on this simulation will compute the structural response to

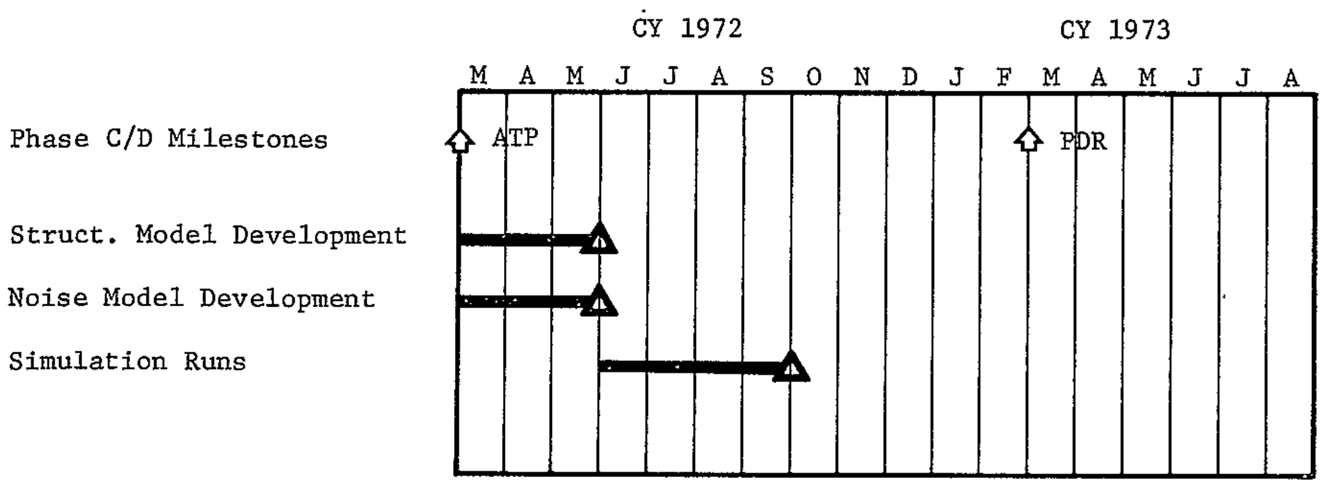
- o lift-off rocket noise
- o transonic boundary-layer turbulence
- o reentry boundary-layer turbulence
- o cruise jet noise
- o landing conditions
- o ground engine run-up

Accuracy considerations will be studied closely to maintain cost-effectiveness in the analysis. Simple models may be used if they produce sufficiently accurate results in order to save computational expense.

There are many existing programs which can perform this analysis that are available for use. NASA's own NASTRAN and MDAC's DYNAL are two prime candidates.

FACILITY: The facility required for this analysis is a large scientifically oriented digital computer.

SCHEDULE: Simulation should be run early in Phase C to establish equipment vibration spectra, crew vibration environment, and impact on airframe design.



SRD 3.2.1.2

DETERMINATION OF BOOSTER AEROELASTIC STABILITY

OBJECTIVE: This simulation will determine the margin of aeroelastic stability of all Booster structural components exposed to air flow, including wings, fins, control surfaces, and thermal protection system panels.

JUSTIFICATION: Airfoil and panel flutter can lead to disastrous structural failures. It often is the limiting factor in establishing minimum allowable airfoil and panel stiffness. Therefore, aeroelastic stability checks must be made at each stage of the design process. Wind tunnel data is costly and impractical in the early stages of vehicle design due to time lags between design and verification. The simulation approach provides rapid feedback. Its results will be checked against wind tunnel data acquired in later design stages.

DESCRIPTION: Aeroelastic stability simulation consists of reducing the mass and stiffness data for a structure to a number of mode shapes and frequencies and then operating on these with an aerodynamic forcing function to obtain stability limitations. This forcing function takes into account the change in the force on a structural element as a result of deformation of the element, thereby introducing the feedback mechanism that results in potential instability. It will compute the pressure distribution on the panel as a function of air speed panel orientation, panel deformation, and air density.

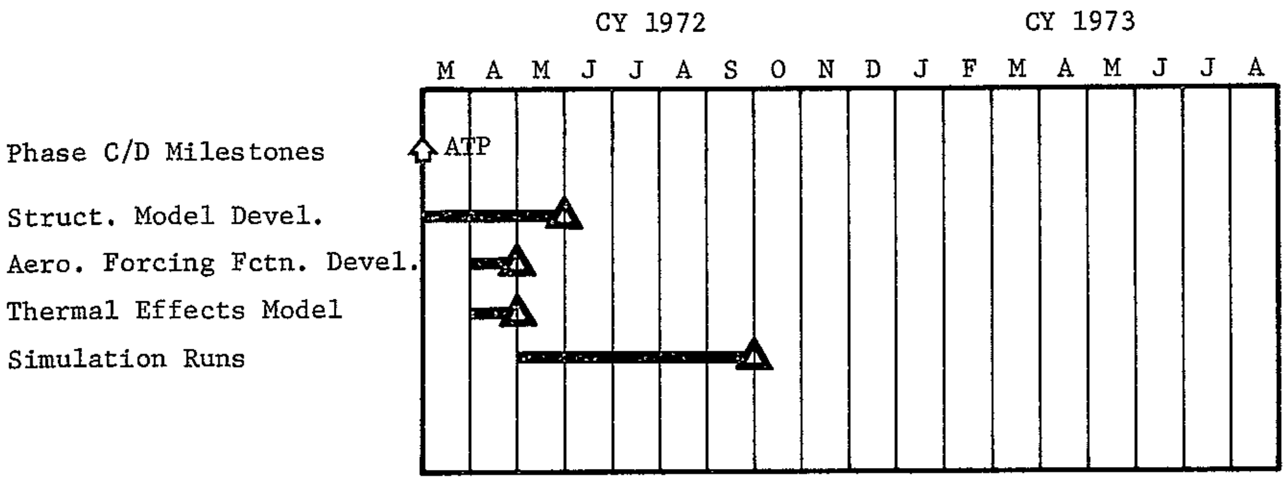
In addition to the aerodynamic and structural models, trajectory information and thermal effects on materials will be required in the simulation. The trajectory information will contain Mach number, dynamic pressure, and temperature time histories upon which the aerodynamic model will operate. The thermal data will be used primarily on the thermal protection system (TPS) panels to take into account the changes in elasticity with changes in the temperature of the panel. Also the effects of panel deformation and buckling due to thermal expansion are included in the model. Thermal effect in control surfaces may also have to be included.

The problem can be broken into pieces to limit the computer capacity for a given run. However, when the wings are analyzed, the fuselage will have to be included because of the coupling due to the delta configuration.

This program will be written in a scientific computing language such as Fortran IV.

FACILITY: This computer simulation may be implemented on a large-scale scientific computer.

SCHEDULE: This simulation should be run early in Phase C to provide input data for structural and TPS panel design.



SRD 3.2.1.3

BOOSTER RESPONSE TO CONTROL SURFACE DEFLECTION

OBJECTIVE: This simulation will determine the compatibility between the Booster elastic structure and the control laws as implemented by the flight control system. Specifically, the program will look for excessive structural loads resulting from human pilot or autopilot control stimuli and for control loop instabilities resulting from the nonrigid nature of the Booster vehicle structure.

JUSTIFICATION: In an elastic vehicle, the vibratory response to sudden or periodic control forces may contribute substantially to the structural loads on certain structural members. Therefore, knowledge of these loads is required in order to ensure an adequate design.

The interaction between the controller (autopilot, human pilot) and the complex mode shapes of the vehicle's aerodynamic surfaces can be simulated only with an equally complex structural model acted upon by expected stimuli. There is no alternative to mathematical modeling other than flying physical models, which is not cost effective.

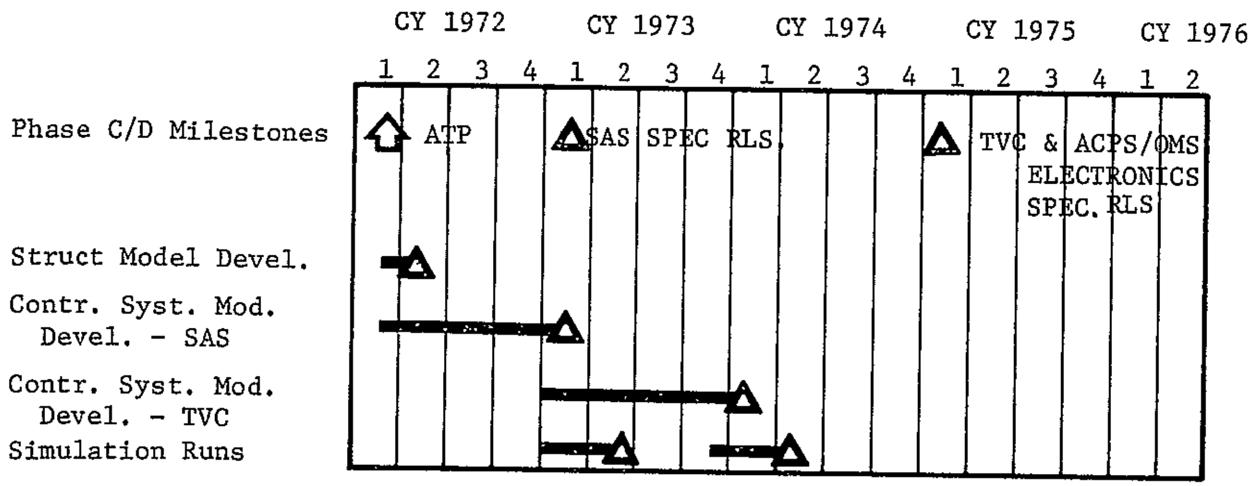
In view of the fact that these models will be used for other simulations, the additional cost will not be great.

DESCRIPTION: This simulation will integrate the Booster finite-element structural model and the flight control system model (including rate and acceleration sensors at their true locations, actuators, and electronics) to form a closed-loop simulation of vehicle flight characteristics. This model will be driven by engine thrusts and aerodynamic forces which will be mathematically modeled. The program will test control loop stability of the system after separation, and during reentry, cruise, and landing. Human pilots will be modeled for those regimes in which a man controls the vehicle.

This simulation program will reveal potential problems resulting from vehicle control systems integration with the elastic body and enable evaluation of control law or structural changes which may be required. This digital computer simulation will utilize Fortran or some other scientific language to model the system elements.

FACILITY: This problem will require a large-scale scientific digital computer.

SCHEDULE: This simulation should be run sufficiently early in structural design and control system design phases to make necessary changes.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1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2
Phase C/D Milestones
ATP
SAS SPEC RLS
TVC & ACPS/OMS ELECTRONICS SPEC. RLS
Struct Model Devel.
Contr. Syst. Mod. Devel. - SAS
Contr. Syst. Mod. Devel. - TVC
Simulation Runs

SRD 3.2.1.4

TRANSIENT RESPONSE OF BOOSTER VEHICLE STRUCTURE TO EXTERNAL LOADS

OBJECTIVE: The objective of this simulation is to evaluate effects of transient disturbances on the Booster vehicle structure during the return phase of the mission. Output of these simulations shall consist of force/displacement time histories resulting from transient disturbances based on statistical input data. Events to be considered in the analysis include:

- o Booster in-flight wind disturbances
- o Separation
- o Landing loads

JUSTIFICATION: Transient inputs to the vehicle structure occurring at various times during the mission can cause resulting loads which may affect the vehicle structure as well as delicate instruments, payloads, or crew. Response of vehicle structures to transient inputs may be evaluated through simulation techniques using existing detailed structural models of the vehicle. These analyses should be conducted early in the development program to determine possible problem areas requiring design change or later verification through physical structural test or flight test.

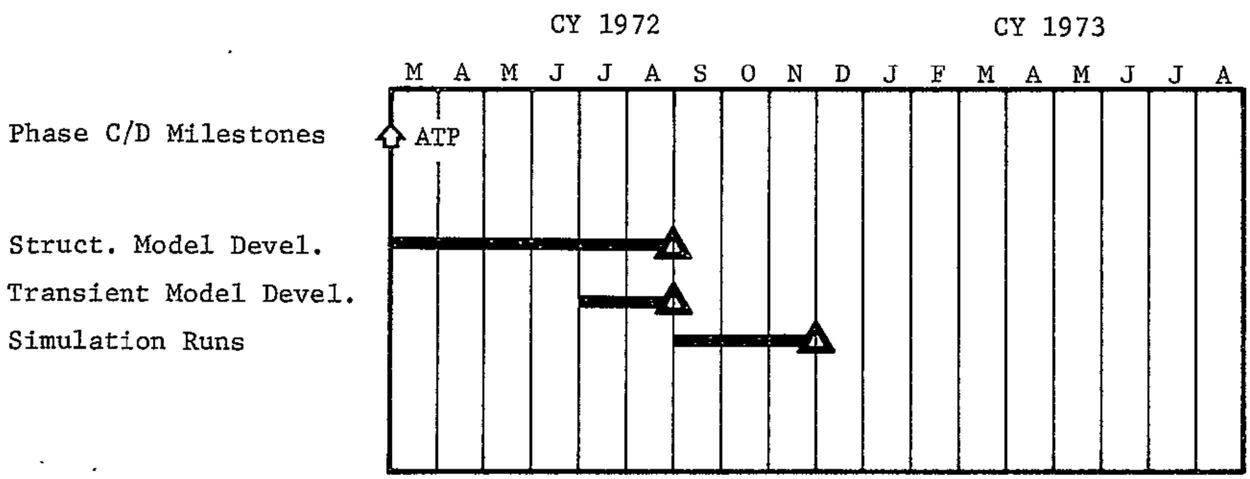
DESCRIPTION: The finite element structural model of the Booster vehicle will be subjected to transient stimuli in order to evaluate resulting structural loads. The characteristics (level, duration, time of occurrence, etc.) of the forcing functions will be described by means of probability distributions based on experimental data. Combinations of these characteristics will then be selected on a statistical basis for simulation runs. The result will be a statistical distribution of bending moments, displacement, etc., which permit a realistic appraisal of the design adequacy.

Mission events represented by the presence of possible excessive load transients are:

- o Booster in-flight wind disturbances - Wind gusts and turbulence effects on the structure in aerodynamic cruise and landing regimes shall be analyzed to verify vehicle structural integrity.
- o Separation dynamics - Separation of the Booster and Orbiter causes transient inputs to both vehicles due to the propulsive shock required to separate the vehicles and to the redistribution of loads as they become separate aerodynamic vehicles. Both normal and abort models shall be analyzed.

- Landing loads - Analyses of landing load transients shall be made to verify structural integrity of vehicle design under variations in landing velocity vehicle attitude at touchdown, vehicle weight, and center of gravity location.

SCHEDULE: The simulation shall be done during structural development phase to verify vehicle response to transient inputs are within design limits.



SRD 3.2.2.1

DETERMINATION OF ORBITER VIBRATION SPECTRA

OBJECTIVE: This simulation will determine the Orbiter structural response to acoustic and boundary layer noise for the purposes of

- o establishing equipment vibration test requirements
- o determining crew vibration environments,
- o determining vibration-induced structural loads on airframe and external panel and support structure.

JUSTIFICATION: Early vibration information is required for design of all spacecraft equipment and subsystems. Early iterations of spacecraft structural design must include vibration loading, especially in the area of external thermal protection system (TPS) panels. Sometimes scaled and modified data from other similar vehicles is used for preliminary design purposes. Simulation is required because this type of data is not available for Shuttle due to the uniqueness of its configuration. The cost of this simulation will be more than offset by the savings in equipment and structural weight made possible by the accurate prediction of vibrational stress.

DESCRIPTION: This simulation will use a finite-element model of the Orbiter structure, plus math models of lift-off rocket noise, transonic boundary layer noise, as well as cruise jet engine noise, including ground engine run-up. Response will then be obtained by means of math models of the structural responses to these acoustic pressures.

The rocket and jet engine noise models including spatial distribution will be constructed from experimental data. Aerodynamic fluctuating pressure data will be obtained from wind tunnel tests.

The distinct computer runs required on this simulation will compute the structural response to

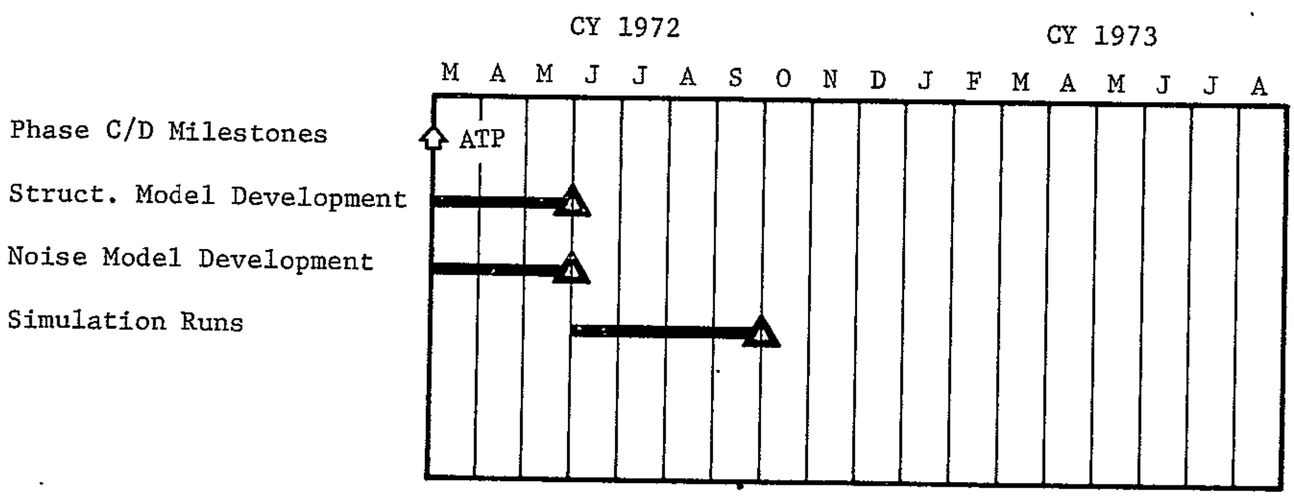
- o lift-off rocket noise
- o transonic boundary-layer turbulence
- o reentry boundary-layer turbulence
- o cruise jet noise
- o landing conditions
- o ground engine run-up

Accuracy considerations will be studied closely to maintain cost-effectiveness in the analysis. Simple models may be used if they produce sufficiently accurate results in order to save computational expense.

There are many existing programs which can perform this analysis that are available for use. NASA's own NASTRAN and MDAC's DYNAL are two prime candidates.

FACILITY: The facility required for this analysis is a large scientifically-oriented digital computer.

SCHEDULE: Simulation should be run early in Phase C to establish equipment vibration spectra, crew vibration environment, and impact of airframe design.



SRD 3.2.2.2

DETERMINATION OF ORBITER AEROELASTIC STABILITY

OBJECTIVE: This simulation will determine the margin of aeroelastic stability of all components exposed to air flow, including wings, fins, control surfaces, and thermal protection system panels.

JUSTIFICATION: Airfoil and panel flutter can lead to disastrous structural failures. It often is the limiting factor in establishing minimum allowable airfoil and panel stiffness. Therefore, aeroelastic stability checks must be made at each stage of the design process. Wind tunnel data is costly and impractical in the early stages of vehicle design due to time lags between design and verification. The simulation approach provides rapid feedback. Its results will be checked against wind tunnel data acquired in later design stages.

DESCRIPTION: Aeroelastic stability simulation consists of reducing the mass and stiffness data for a structure to a number of mode shapes and frequencies, and then operating on these with an aerodynamic forcing function to obtain stability limitations. This forcing function takes into account the change in the force on a structural element as a result of deformation of the element, thereby introducing the feedback mechanism that results in potential instability. It will compute the pressure distribution on the panel as a function of air speed, panel orientation, panel deformation, and air density.

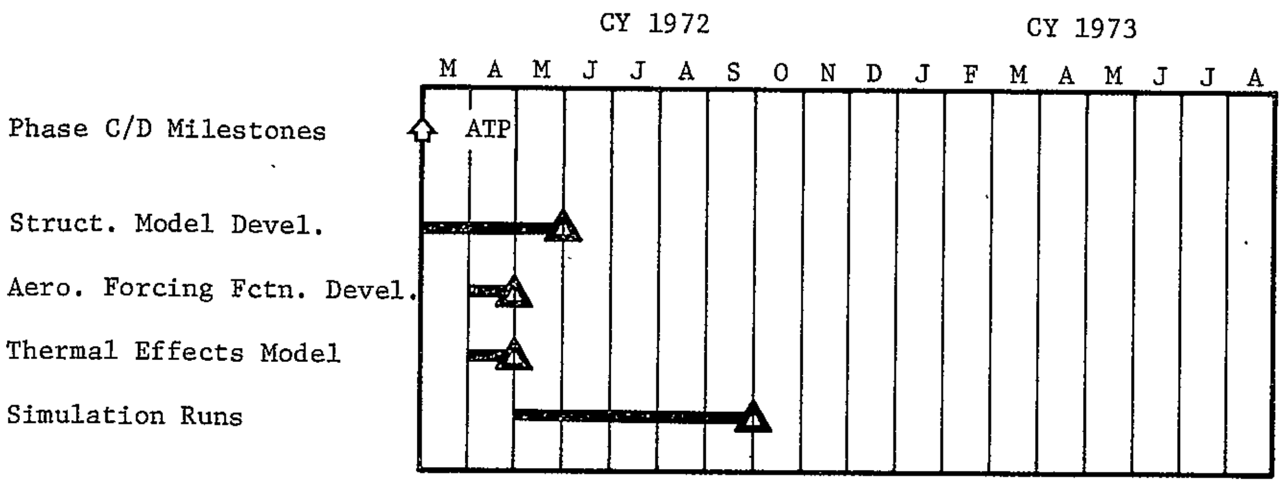
In addition to the aerodynamic and structural models, trajectory information and thermal effects on materials will be required in the simulation. The trajectory information will contain Mach number, dynamic pressure, and temperature time histories upon which the aerodynamic model will operate. The thermal data will be used primarily on the thermal protection system (TPS) panels to take into account the changes in elasticity with changes in the temperature of the panel. Also, the effects of panel deformation and buckling due to thermal expansion are included in the model. Thermal effects in control surfaces may also have to be included.

The problem can be broken into pieces to limit the computer capacity for a given run. However, where the wings are analyzed, the fuselage will have to be included because of the coupling due to the delta configuration.

This program will be written in a scientific computing language such as Fortran IV.

FACILITY: This computer simulation may be implemented on a large-scale commercial scientific computer.

SCHEDULE: This simulation should be run early in Phase C to provide input data for structural and TPS panel design.



SRD 3.2.2.3

ORBITER VEHICLE STRUCTURAL - PROPULSION STABILITY

OBJECTIVE: This simulation will determine the extent of vehicle oscillation due to coupling between structural vibration modes and engine thrust. It will serve as a tool for the evaluation of design changes affecting this potentially unstable interaction. Outputs of this simulation shall include:

- o Detailed data representing overall system response to propulsion/ structural dynamic coupling (POGO).
- o Evaluation of effects of POGO instabilities and determination of suppression requirements in terms of crew, equipment, and structural safety margins.
- o Evaluation of candidate POGO suppression devices and final selection.
- o Analysis of uncertainties in developing the structural/propulsion model and possible effects on final data.

JUSTIFICATION: POGO vibration can, if allowed to become excessive, overstress the airframe, damage sensitive instruments, such as gyros and accelerometers, and create an intolerable crew environment.

This phenomenon cannot be observed by test prior to first vertical flight. Therefore, mathematical simulation represents the only means of analysis.

The POGO problem on other less complicated structures required considerable attention in order to avoid severe problems. Therefore, it is imperative that it receive adequate attention on Shuttle.

DESCRIPTION: The POGO problem arises in large-scale liquid-propellant propulsion systems with long longitudinal feedlines. The mechanism is initiated by the thrust of the engines. This force compresses the elastic vehicle longitudinally. The structure springs back and longitudinal oscillations occur. These compressions and elongations set up spatial and temporal variations in propellant pressure along the liquid oxygen (LOX) feedlines. The resulting varying pressure at the engines' oxidizer inlets causes thrust variations which can then reinforce the structural oscillations. In addition, this vehicle is nonaxisymmetric. As a result, significant coupling exists between lateral and longitudinal vibration. The lengthy lateral LOX feedline runs will react to these lateral vibrations complicating the problem further.

The simulation of the POGO phenomenon requires detailed math models of the vehicle structure and the engine and fuel systems coupled with the vehicle equations of motion for the various trajectories during the boost phase of flight after

separation from the Booster. The models will include time-varying parameters and nonlinear effects to produce as complete a model as possible. Uncertainty will exist as to the exact values of the model parameters. A worst-case type analysis will be performed if the worst-case combination of parameter values can be determined. The computational expense of a single point analysis is far less than that of a Monte Carlo approach. Nonetheless, the Monte Carlo technique will be used if the worst-case conditions cannot be determined or if the worst-case response cannot be suppressed and is, at the same time, very unlikely to occur.

The simulation will require the use of hybrid facilities and techniques. The digital portion will include the six-degree-of-freedom finite-element model of the structure and the engine model program supplied by the engine manufacturer. The engine deck should contain transfer functions determined on the basis of dynamic tests on the latest engine version possible in order to minimize the uncertainty in the model. The data from these tests should provide engine pressure gain and flow impedance over the flight operating range of pump inlet pressure and engine mixture ratio.

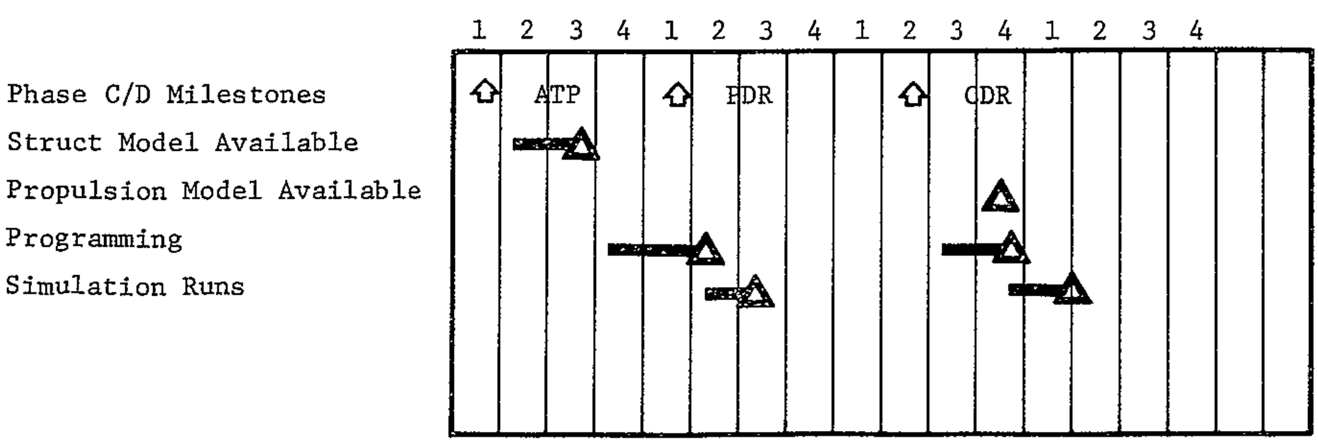
The analog portion of the simulation will contain at least the trajectory data because of the vast amount of digital storage that would be required otherwise. It may also contain the fluid mechanical transfer functions.

The results of the simulation will include:

- The POGO-suppression configuration required
- The POGO-induced vibrational environments.

FACILITY: A hybrid facility containing large-scale digital and analog computers (CEC 6600, MILGO 4100 or equivalent) and standard peripherals.

SCHEDULE: Early simulations should be run to obtain preliminary data on magnitude of POGO effects. Later simulations using updated models will provide additional accuracy.



SRD 3.2.2.4

ORBITER RESPONSE TO CONTROL SURFACE DEFLECTION

OBJECTIVE: This simulation will determine the compatibility between the Orbiter elastic structure and the control laws as implemented by the flight control system. Specifically, the program will look for excessive structural loads resulting from human pilot or autopilot control stimuli and for control loop instabilities resulting from the nonrigid nature of the Orbiter vehicle structure.

JUSTIFICATION: In an elastic vehicle, the vibratory response to sudden or periodic control forces may contribute substantially to the structural loads on certain structural members. Therefore, knowledge of these loads is required in order to ensure an adequate design.

The interaction between the controller (autopilot, human pilot) and the complex mode shapes of the vehicle's aerodynamic surfaces can be simulated only with an equally complex structural model acted upon by expected stimuli. There is no alternative to mathematical modeling other than flying physical models, which is not cost effective.

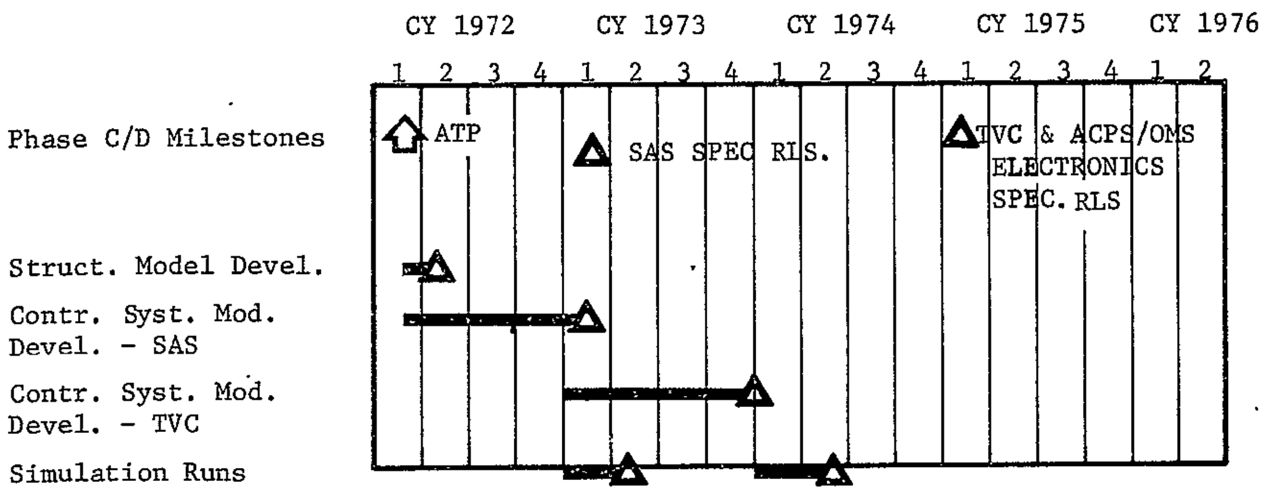
In view of the fact that these models will be used for other simulations, the additional cost will not be great.

DESCRIPTION: This simulation will integrate the Orbiter finite-element structural model, the propellant sloshing forces model, and the flight control system model (including rate and acceleration sensors at their true locations, actuators, and electronics) to form a closed-loop simulation of vehicle flight characteristics. This model will be driven by engine thrusts and aerodynamic forces which will be mathematically modeled. The program will test control loop stability of the system ater separation, and during reentry, cruise, and landing.
Human pilots will be modeled for those regimes in which a man controls the vehicle. This simulation program will reveal potential problems resulting from vehicle control system interaction with the elastic body and enable evaluation of control law or structural changes which may be required.

This digital computer simulation will utilize Fortran or some other scientific language to model the system elements.

FACILITY: This problem will require a large-scale scientific digital computer.

SCHEDULE: The simulation will be conducted in two phases: response to stability augmentation system will be analyzed followed by thrust vector control system analysis.


CY 1972
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CY 1976
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2
Phase C/D Milestones
ATP
SAS SPEC RLS.
TVC & ACPS/OMS ELECTRONICS SPEC. RLS
Struct. Model Devel.
Contr. Syst. Mod. Devel. - SAS
Contr. Syst. Mod. Devel. - TVC
Simulation Runs

SRD 3.2.2.5

ORBITER CONTROL IN THE PRESENCE OF POGO

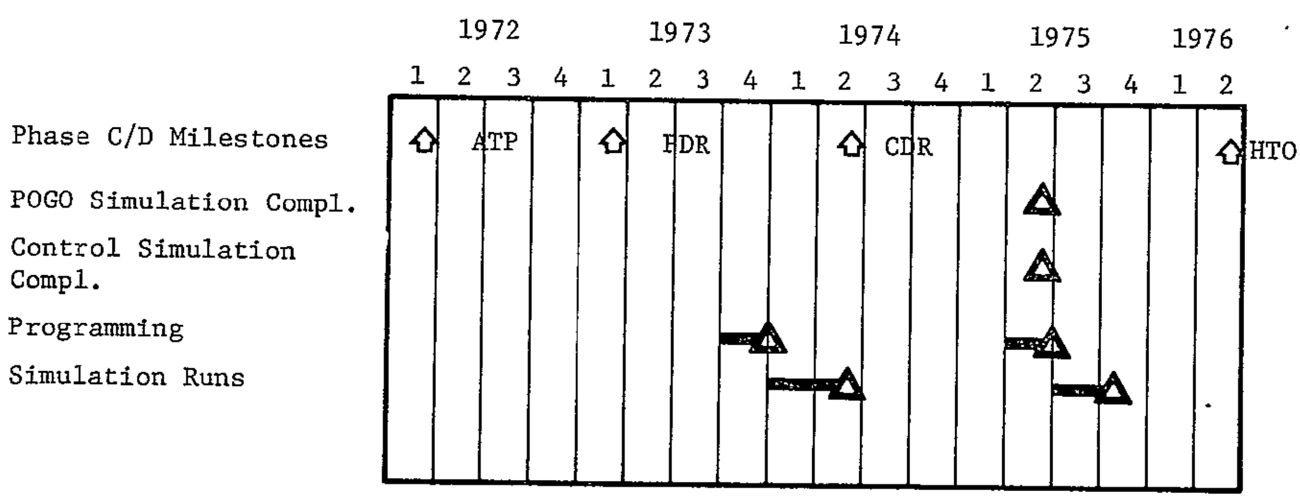
OBJECTIVE: This simulation will examine the controllability of Orbiter vehicle in the presence of POGO oscillations to determine if autopilot natural frequencies can excite excessive POGO oscillations. The simulation will allow parametric variation in the autopilot while observing stability of the vehicle.

JUSTIFICATION: It is necessary to determine whether pitch control system interaction with POGO is adverse, helpful, or negligible during the Orbiter boost phase. There is no satisfactory alternative to a system math model and computer simulation to determine whether a problem exists and to what extent. Simulation techniques permit observation of control system/POGO interaction prior to actual test flights.

DESCRIPTION: This simulation will combine the models used in SRD 3.2.2.3 and SRD 3.2.2.4 to determine the effect of the flight control system on POGO oscillations. A worst-case analysis will be performed if the worst-case combination of parameter values can be determined. This analysis will not be sufficient if the combination of parameter values is highly unlikely while, at the same time, the resulting POGO oscillations cannot be adequately suppressed by candidate suppression devices. In this case, a Monte Carlo approach will be required to obtain a reasonable distribution on the system response.

FACILITY: A hybrid facility containing large-scale digital and analog computer (CDC 6600, MILGO 4100, or equivalent) and standard peripherals.

SCHEDULE: This simulation shall be run upon completion of SRD 3.2.2.3 as a continuation of POGO analysis.



SRD 3.2.2.6

TRANSIENT RESPONSE OF ORBITER VEHICLE STRUCTURE TO EXTERNAL LOADS

OBJECTIVE: The objective of this simulation is to evaluate effects of transient disturbances on the Orbiter vehicle structure during orbital and return phases of the mission. Output of these simulations shall consist of force and displacement time histories resulting from transient disturbances based on statistical input data. Events to be considered in this analysis include:

- o separation
- o engine ignition and shutdown
- o in-flight wind disturbances
- o docking
- o landing loads

JUSTIFICATION: Transient inputs to the vehicle structure occuring at various times during the mission can cause resulting loads which may effect the vehicle structure as well as delicate instruments, payloads, or crew. Response of vehicle structures to transient inputs may be evaluated through simulation techniques using existing detailed structural models of the vehicle. These analyses should be conducted early in the development program to determine possible problem areas requiring design change or later verification through physical structural test or flight test.

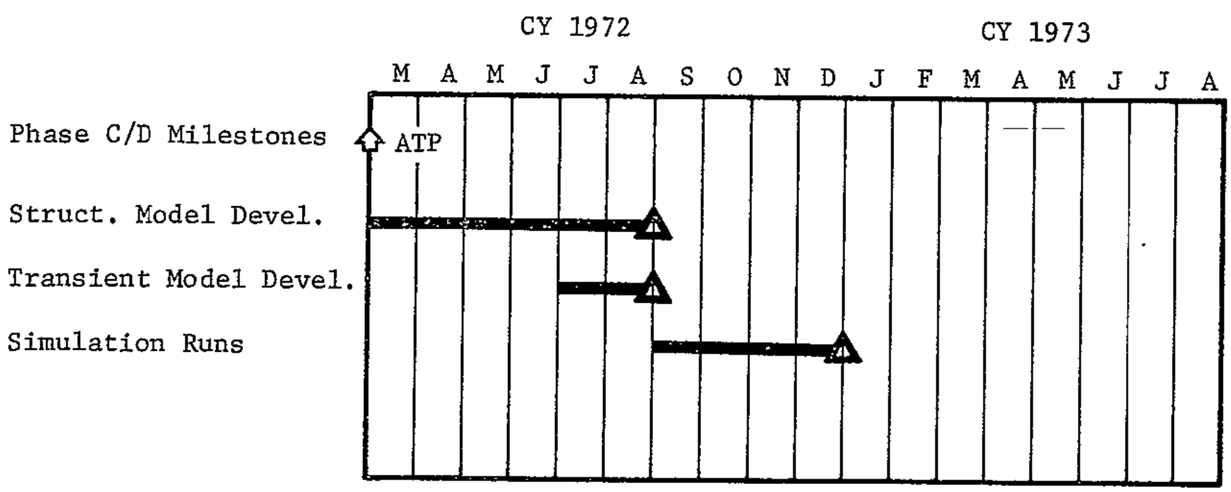
DESCRIPTION: The finite element structural model of the Orbiter vehicle will be subjected to transient stimuli in order to evaluate resulting structural loads. The characteristics (level, duration, time of occurrence, etc.) of the forcing functions will be described by means of probability distributions based on experimental data. Combinations of these characteristics will then be selected on a statistical basis for simulation runs. The result will be a statistical distribution of bending moments, displacement, etc., which permit a realistic appraisal of the design adequacy. Mission events represented by presence of possible excessive load transients are:

- o Separation dynamics - Separation of the Booster and Orbiter causes transient inputs to both vehicles due to the propulsive shock required to separate the vehicles and the redistribution of loads as they become separate aerodynamic vehicles. Both normal and abort modes shall be analyzed.

- Ir-flight wind disturbances - Wind gusts and turbulence effects on the structure in aerodynamic cruise and landing regimes shall be analyzed to verify vehicle structural integrity.
- Orbiter engine ignition and shutdown - The transient conditions upon engine ignition are similar in nature to the launch vehicle at ignition except the Orbiter is in an aerodynamic environment which must be taken into consideration. Both ignition and shutdown transients may be generated by unsymmetrical thrust buildup and decay, different burning terms and effects of engine misalignment.
- Docking - Actual contact with the target vehicle or space station may cause load transients on the vehicle which should be analyzed as to possible effects on the structure. Various impulses and angles of contact shall be evaluated.
- Landing loads - Analysis of landing loads transients shall be made to verify structural integrity of vehicle design under variations in landing velocity, vehicle attitude at touchdown, vehicle weight, and center of gravity location.

FACILITY: This simulation will require a scientifically-oriented digital computer such as the CDC 6600.

SCHEDULE: The simulation shall be done during structural development to verify vehicle response to transient inputs is within design limits.



SRD 3.2.3.1

COMBINED VEHICLE STRUCTURAL - PROPULSION STABILITY

OBJECTIVE: This simulation will determine the extent of vehicle oscillation due to coupling between structural vibration modes and engine thrust. It will serve as a tool for the evaluation of design changes affecting this potentially unstable interaction. Outputs of this simulation shall include:

- Detailed data representing overall system response to propulsion/structural dynamic coupling (POGO).
- Evaluation of effects of POGO instabilities and determination of suppression requirements in terms of crew, equipment, and structural safety margins.
- Evaluation of candidate POGO suppression devices and final selection.
- Analysis of uncertainties in developing the structural/propulsion model and possible effects on final data.

JUSTIFICATION: POGO vibration can, if allowed to become excessive, overstress the airframe, damage sensitive instruments, such as gyros and accelerometers, and create an intolerable crew environment.

This phenomenon cannot be observed by test prior to first vertical flight. Therefore, mathematical simulation represents the only means of analysis.

The POGO problem on other less complicated structures required considerable attention in order to avoid severe problems. Therefore, it is imperative that it receive adequate attention on Shuttle.

DESCRIPTION: The POGO problem arises in large-scale liquid-propellant propulsion systems with long longitudinal feedlines. The mechanism is initiated by the thrust of the engines. This force compresses the elastic vehicle longitudinally. The structure springs back and longitudinal oscillations occur. These compressions and elongations set up spatial and temporal variations in propellant pressure along the liquid oxygen (LOX) feedlines. The resulting varying pressure at the engines' oxidizer inlets causes thrust variations which can then reinforce the structural oscillations. In addition, this vehicle is nonaxisymmetric. As a result, significant coupling exists between lateral and longitudinal vibration. The lengthy lateral LOX feedline runs will react to these lateral vibrations complicating the problem further.

The simulation of the POGO phenomenon requires detailed math models of the vehicle structure and the engine and fuel systems coupled with the vehicle equations of motion for the various trajectories during the boost phase of flight before separation. The models will include time-varying parameters and nonlinear effects to produce as complete a model as possible. Uncertainty will exist as to the exact values of the model parameters. A worst-case type analysis will be performed if the worst-case combination of parameter values can be determined. The computational expense of a single point analysis is far less than that of a Monte Carlo approach. Nonetheless, the Monte Carlo technique will be used if the worst-case conditions cannot be determined or if the worst-case response cannot be suppressed and is, at the same time, very unlikely to occur.

The simulation will require the use of hybrid facilities and techniques. The digital portion will include the six-degree-of-freedom finite-element model of the structure and the engine model program supplied by the engine manufacturer. The engine deck should contain transfer functions determined on the basis of dynamic tests on the latest engine version possible in order to minimize the uncertainty in the model. The data from these tests should provide engine pressure gain and flow impedance over the flight operating range of pump inlet pressure and engine mixture ratio.

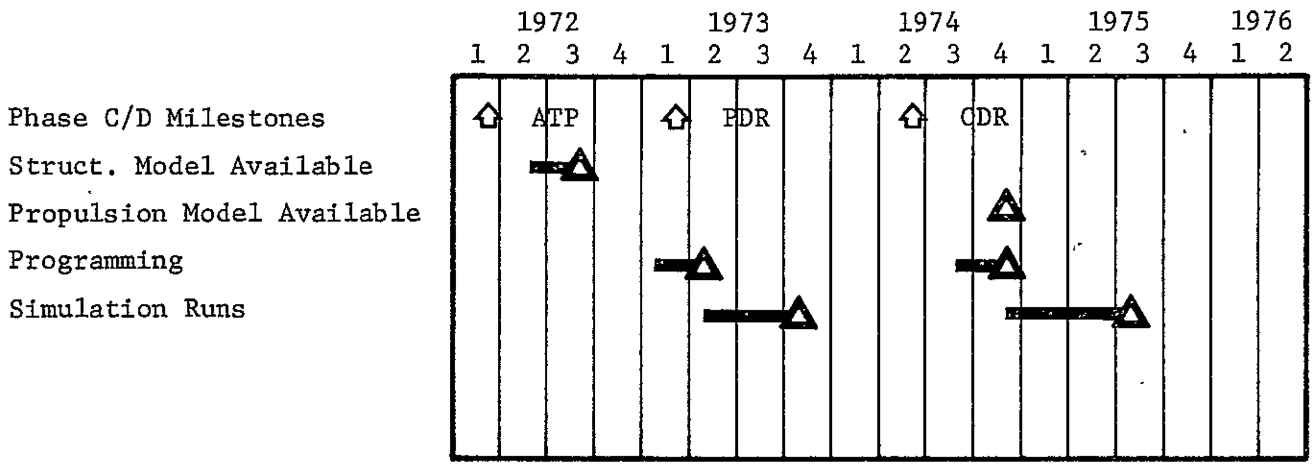
The analog portion of the simulation will contain at least the trajectory data because of the vast amount of digital storage that would be required otherwise. It may also contain the fluid mechanical transfer functions.

The results of the simulation will include:

- The POGO-suppression configuration required
- The POGO-induced vibrational environments.

FACILITY: A hybrid facility containing large-scale digital and analog computers (CEC 6600, MILGO 4100, or equivalent) and standard peripherals.

SCHEDULE: Early simulations should be run to obtain preliminary data on magnitude of POGO effects; later simulations using updated models provide additional accuracy.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Phase C/D Milestones
ATP
PDR
CDR
Struct. Model Available
Propulsion Model Available
Programming
Simulation Runs

SRD 3.2.3.2

COMBINED ORBITER/BOOSTER VEHICLE RESPONSE
TO CONTROL SURFACE DEFLECTION

OBJECTIVE: This simulation will determine the compatibility between the combined vehicle elastic structure and the control laws as implemented by the flight control system. Specifically, the program will look for excessive structural loads resulting from human pilot or autopilot control stimuli and for control loop instabilities resulting from the nonrigid nature of the combined vehicle structure.

JUSTIFICATION: In an elastic vehicle, the vibratory response to sudden or periodic control forces may contribute substantially to the structural loads on certain structural members. Therefore, knowledge of these loads is required in order to ensure an adequate design.

The interaction between the controller (autopilot, human pilot) and the complex mode shapes of the vehicle's aerodynamic surfaces can be simulated only with an equally complex structural model acted upon by expected stimuli. There is no alternative to mathematical modeling other than flying physical models, which is not cost effective.

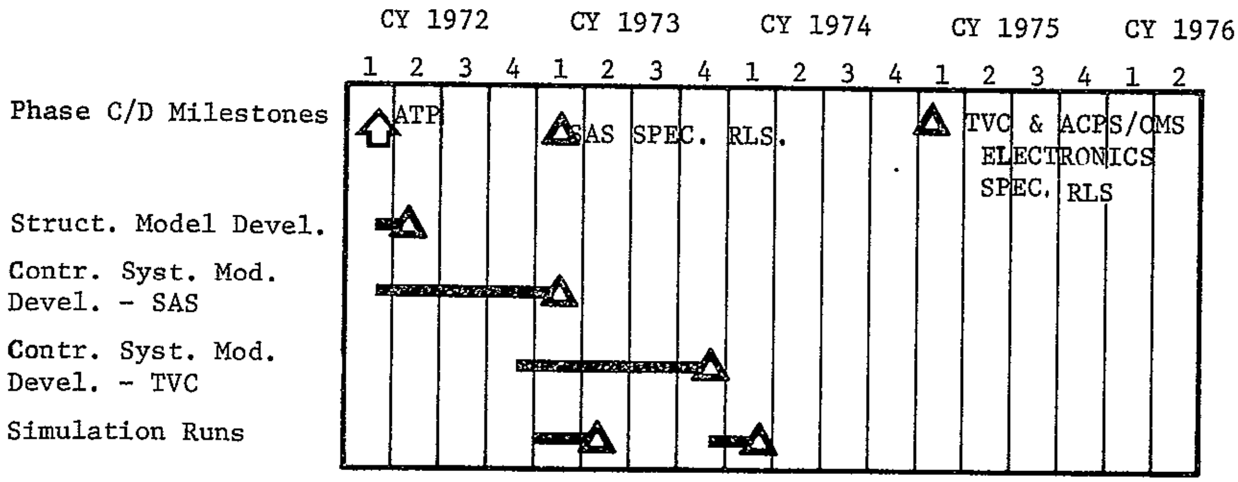
In view of the fact that these models will be used for other simulations, the additional cost will not be great.

DESCRIPTION: This simulation will integrate the Orbiter finite-element structural model (including rate and acceleration sensors at their true locations, actuators, and electronics) to form a closed-loop simulation of vehicle flight characteristics. This model will be driven by engine thrusts and aerodynamic forces which will be mathematically modeled. The program will test control loop stability of the system. Human pilots will be modeled for the situation in which a man may control the vehicle. This simulation program will reveal potential problems resulting from vehicle control system interaction with the elastic body and enable evaluation of control law or structural changes which may be required.

This digital computer simulation will utilize Fortran or some other scientific language to model the system elements.

FACILITY: This problem will require a large-scale scientific digital computer.

SCHEDULE: This simulation should be run sufficiently early in structural design and control system design phases to make necessary changes.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Phase C/D Milestones
ATP
SAS SPEC. RLS.
TVC & ACPS/OMS ELECTRONICS SPEC. RLS
Struct. Model Devel.
Contr. Syst. Mod. Devel. - SAS
Contr. Syst. Mod. Devel. - TVC
Simulation Runs

SRD 3.2.3.3

SIMULATION OF COMBINED VEHICLE CONTROL IN THE PRESENCE OF POGO

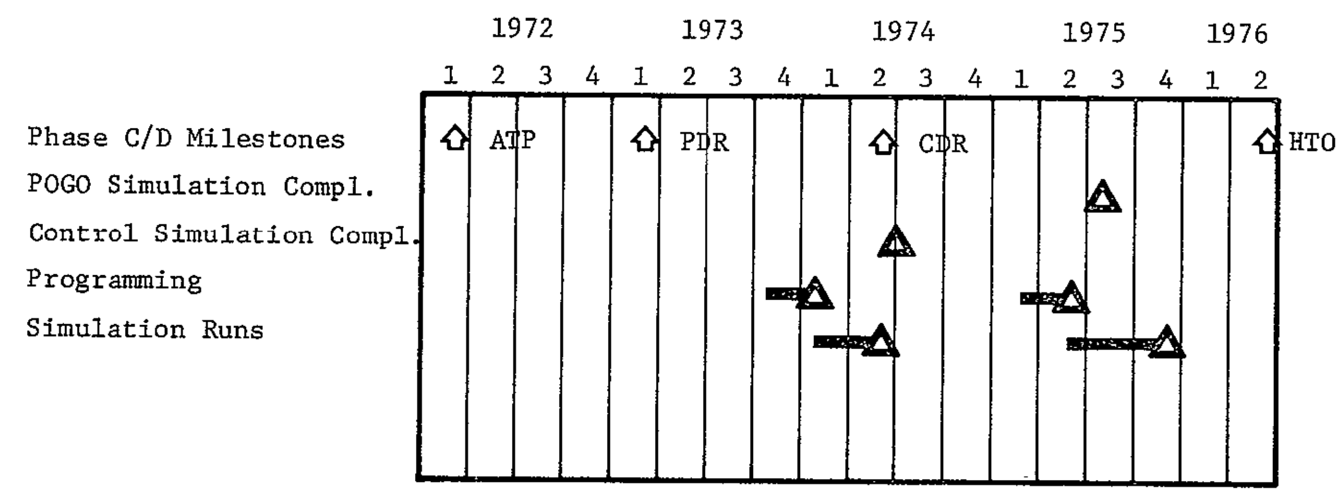
OBJECTIVE: This simulation will examine the controllability of the combined vehicle in the presence of POGO oscillation to determine if autopilot natural frequencies can excite excessive POGO oscillations. The simulation will allow parametric variation in the autopilot while observing stability of the vehicle.

JUSTIFICATION: The nonaxisymmetric, "piggy-back" configuration of the combined vehicle exhibits relatively strong coupling between longitudinal and lateral motions. This indicates that an interaction will take place between the POGO motion (longitudinal) and the forces exerted by the flight control system (lateral). Whether or not this interaction is inherently stabilizing, destabilizing, or negligible, its effect must be known in order to avoid risking inadequate design. The only practical way to observe the phenomenon is to simulate it mathematically.

DESCRIPTION: This simulation will combine the models used in SRD 3.2.3.1 and SRD 3.2.3.2 to determine the effect of the flight control system on POGO oscillations. The alternative approaches outlined in SRD (POGO) are applicable here as well, with the exception that the pitch control autopilot model is included in either analog or digital form depending on the analysis technique chapter. The output of the simulation will be stability evaluations in either the time domain or frequency domain for alternative autopilot design and parametric values.

FACILITY: A hybrid facility containing large-scale digital and analog computer (CDC 6600, MILGO 4100, or equivalent) and standard peripherals.

SCHEDULE: This simulation shall be run upon completion of SRD 3.2.3.1 as a continuation of POGO analysis.



SRD 3.2.3.4

TRANSIENT RESPONSE OF COMBINED VEHICLE STRUCTURE TO EXTERNAL LOADS

OBJECTIVE: The objective of this simulation is to evaluate effects of the combined Booster and Orbiter launch vehicle during the ascent phase. Output of these simulations shall consist of force/displacement time histories resulting from transient disturbances based on statistical input data. Events to be analyzed include:

- o Booster main engine ignition
- o Liftoff
- o Ascent wind disturbances
- o Booster main engine shutdown

JUSTIFICATION: Transient inputs to the vehicle structure occurring at various times during the mission can cause resulting loads which may affect the vehicle structure as well as delicate instruments, payloads, or crew. Response of vehicle structures to transient inputs may be evaluated through simulation techniques using existing detailed structural models of the vehicle. These analyses should be conducted early in the development program to determine possible problem areas requiring design change or later verification through physical structural test or flight test.

DESCRIPTION: The finite element structural model of the combined vehicle will be subjected to transient stimuli in order to evaluate resulting structural loads. The characteristics (level, duration, time of occurrence, etc.) of the forcing functions will be described by means of probability distributions based on experimental data. Combinations of these characteristics will then be selected on a statistical basis for simulation runs. The result will be a statistical distribution of bending moments, displacement, etc., which permit a realistic appraisal of the design adequacy.

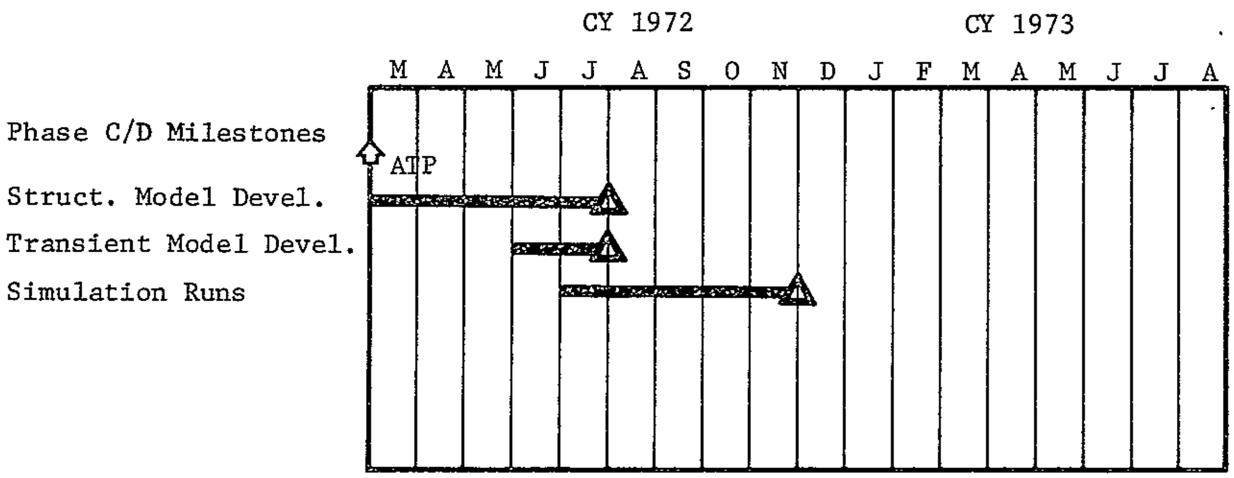
Mission events represented by the presence of possible excessive load transients are:

- o Booster engine ignition - The vehicle structure is subjected to transient loads upon ignition resulting in application of forces and moments to the hold-down structure.
- o Liftoff dynamics - Structure of the launch configured vehicle can be affected by liftoff transients caused by sudden release of restraining forces and moments, wind gusts at liftoff engine misalignment and asymmetrical thrust buildup.

- Ascent wind disturbances - Wind gusts, turbulence, and wind shear effects on the vehicle during ascent create complex loading patterns which will have significant effect because of the launch vehicle winged configuration restriction on wind conditions at launch may be necessary depending on results of analysis.
- Booster engine thrust decay - Asymmetric engine shutdown and resulting gimbaling of the main engines may cause transient inputs to the launch vehicle structure.

FACILITY: This simulation will require a scientifically-oriented digital computer such as the CDC 6600.

SCHEDULE: The simulation shall be done during structural development phase to verify vehicle response to transient inputs is within design limits.



SRD 4.1.1.1

BOOSTER FLIGHT CONTROL SYSTEM SIMULATIONS

OBJECTIVE: The objective of this simulation is to evaluate the performance of Booster flight control system automatic modes of operation. Outputs will consist of:

- Firm definition of flight control system gains coefficients, deadbands, and threshold.
- Evaluation of control margins adequacy
- Definition of allowable center of gravity trend
- Definition of attitude control system fuel requirements

JUSTIFICATION: These simulations are required to verify adequacy of the Booster flight control system concepts prior to their translation into flight software, hardware, and fuel requirements.

DESCRIPTION: Math models of the onboard control system operational modes will be interfaced with the applicable reference environment (Appendix B) and executed to provide performance data. The types of control to be simulated are thrust vector control, (main engine gimbal) reaction jet control, aerodynamic surfaces control, and combinations of the three. Parameters required from the environment simulation (Appendix B) to be used as control signals are shown in the following table for the appropriate mission phase.

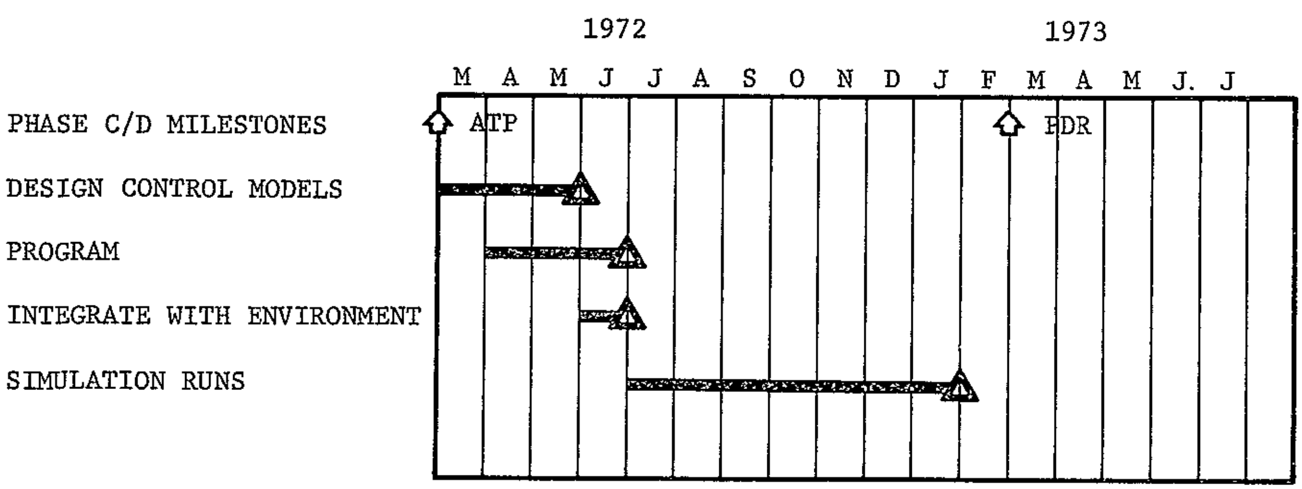
CONTROL SIGNAL \ MISSION PHASE	ASCENT	ENTRY	TRANSITION	AERO-DYNAMIC
Body Angular Rates	X	X	X	X
Body Attitude	X	X	X	X
Body Accelerations			X	X
Altitude			X	X
Range to Runway				X
Glide Slope Angle				X
Heading Angle				X
Bank Angle			X	X
Angle of Attack			X	X
True Airspeed			X	X

The flight control system simulations covered by this SRD will be used to obtain booster, and mated vehicle theoretical performance figures. That is, the control system and control signals are assumed to be perfect, but the maximum control torques are actual rates. Input data required for execution of these simulations fall into two major groups, environment and control system. Data describing the vehicle mass properties, initial state vector, vehicle and control surfaces aerodynamic coefficients, control moments, atmosphere, and winds are required for the environment group. Polynominal coefficients, gains, deadbands, and thresholds must be defined for the control system model.

The flight control system simulation will be written in a common scientific language (e.g., Fortran) and should interface with the simulated reference environment software package.

FACILITY: A general purpose digital computer with standard peripherals will be required for executing this simulation.

SCHEDULE: This simulation must be completed prior to generating detailed FCS hardware and software requirements specifications.



SRD 4.1.1.2

BOOSTER NAVIGATION SYSTEM SIMULATION

OBJECTIVE: The objective of this simulation is to evaluate the performance of the various types of navigation system configurations for the appropriate mission phase. Outputs will include:

- o Evaluation of sensitivity to errors in initial conditions and navigation sensor inputs
- o Evaluation of integration techniques, step size and error detection
- o Evaluation of update selection criteria
- o Evaluation of ground navigation aid selection criteria

JUSTIFICATION: These simulations are required to verify the capability of the navigation systems to fulfill mission requirements.

DESCRIPTION: The following forms of navigation have been identified for use in the booster as indicated:

- o Powered flight navigation - This navigation method consists of real-time integration of sensed accelerations and calculated gravitational acceleration. Calculations are performed in an inertial reference frame.
- o Coasting navigation - This method of navigation is an integration of computed accelerations, gravitational and aerodynamic. Integration is performed in discrete steps rather than real time (i.e., one step per minute).
- o Ground aided navigation - This navigation uses VOR/DME or DME/DME information to locate the vehicle with respect to the navigation aids. Approach mode uses ILS and glide slope information.

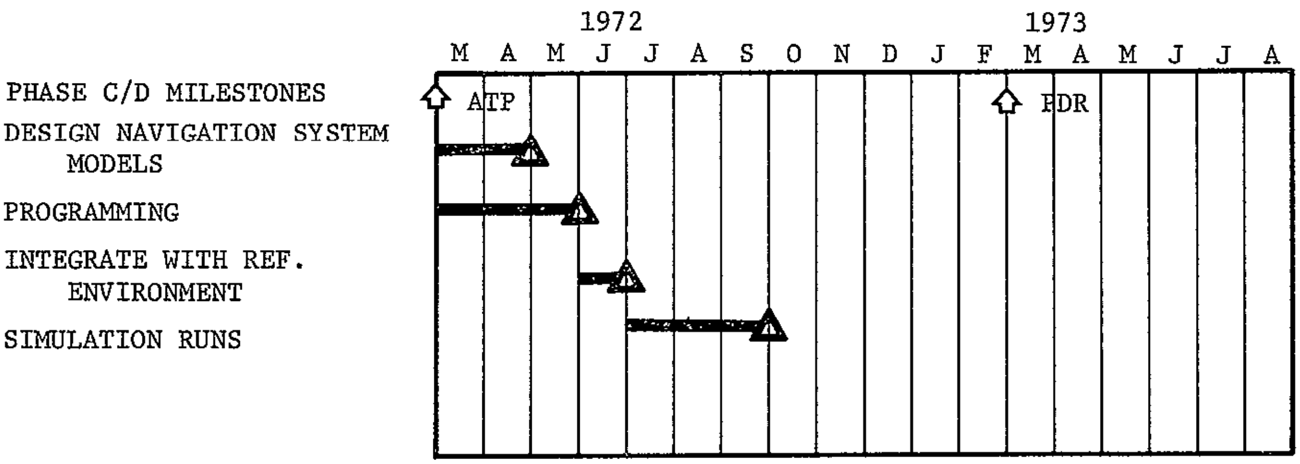
The mission phases that use these navigation methods are shown in the following table:

NAVIGATION TYPE \ MISSION PHASE	ASCENT	ENTRY	TRANSITION	AERODYNAMIC
Powered Flight	X	X	X	X
Coast	X	X		
Ground Aided				X

The simulations covered by this SRD will be used to determine booster and mated vehicle navigation subsystem performance based upon perfect sensor data and math models of the onboard navigation systems. These models will be interfaced with the environment program described in Appendix B. In addition to this input, data will be required to define integration intervals, initial navigation state vector, onboard estimates of aerodynamic coefficients, VOR/DME catalog, and ILS data. The simulation will be written in a common scientific language.

<u>FACILITY</u>: A general purpose digital computer with standard peripherals will be required to perform these simulations.

<u>SCHEDULE</u>: These simulations are required to be performed prior to flight software design activities.



SRD 4.1.1.3

BOOSTER GUIDANCE AND TARGETING SIMULATIONS

OBJECTIVE: The objective of this simulation is to evaluate various targeting and guidance concepts for the different mission phases. Outputs will include:

- Evaluation of ascent and landing targeting methods
- Evaluation of performance of the guidance schemes with respect to position, velocity, altitude errors and fuel requirements.

JUSTIFICATION: Onboard targeting and guidance techniques must be verified to satisfy mission requirements within specified accuracies, and provide necessary input data for flight software (guidance modules) development.

DESCRIPTION: Simulations to evaluate equations for the Booster ascent and landing targeting problems and guidance equations for ascent, ascent abort, re-entry, and terminal area energy management phases are covered by this simulation requirement.

The ascent targeting equations will determine launch time and cutoff conditions based upon rendezvous target ephemeris and desired orbital conditions. The landing targeting problem consists of determining reentry maneuver and time information required to land at a selected site within a given time interval.

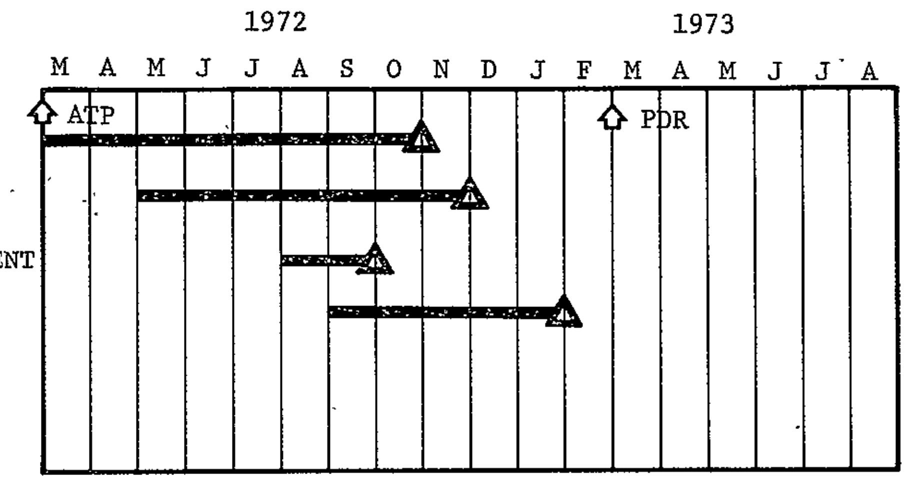
The guidance concepts are evaluated assuming all required translational and attitude maneuvers, and navigations are performed perfectly. Guidance system performance will be specified as errors with respect to the desired condition, fuel penalties, required time, or whatever is applicable to the particular simulation. Uncertainties in the environmental models and the resultant effect on the guidance system performance will be determined by varying the appropriate model input data.

This SRD is intended to cover simulations for the booster and mated vehicle guidance systems. These simulation programs will interface with the reference environment program (Appendix B) which requires input data describing vehicle mass properties, initial state vector, aerodynamics, atmosphere, winds, target data, landing site, vehicle propulsion capabilities, and control torques.

FACILITY: A general purpose digital computer with standard peripherals will be required for these simulation programs.

SCHEDULE: These simulations must be completed prior to flight software requirements definitions.

- PHASE C/D MILESTONES
- DESIGN MAIN MODELS
- PROGRAM
- INTEGRATE WITH ENVIRONMENT
- SIMULATION RUNS



SRD 4.1.1.4

BOOSTER CLOSED-LOOP PERFORMANCE

OBJECTIVE: The purpose of this task is to evaluate the overall guidance, navigation and control subsystems concepts operating as an integrated function in a closed-loop, all-digital, six-degree-of-freedom, rigid-body simulation. Outputs will include:

- o errors with respect to reference or targeting conditions for various error sources; environmental, flight hardware and flight software
- o evaluation of closed-loop fuel requirements
- o definition of flight software requirements

JUSTIFICATION: These simulations are required to verify the adequacy of design of the Booster guidance navigation and control subsystems meeting mission objectives.

DESCRIPTION: The computer simulations necessary to conduct closed-loop performance analysis of the Booster guidance, navigation and control subsystems for all mission phases are covered by this simulation requirements description. Basically these simulations are extensions of appropriate combinations of the program described in SRD's 4.1.1.1, 4.1.1.2, and 4.1.1.3. Initial investigations using the simulation programs covered by this description shall be directed toward determining that the integrated guidance navigation and control subsystems will interface satisfactorily. Subsequent investigations shall be conducted to obtain more complete knowledge of the subsystem operating characteristics.

Math models of the guidance, navigation and control subsystems previously written to interface with the reference environment (Appendix B) will be modified to interface with each other. In addition, math models for various onboard guidance and navigation sensors will be developed and include for use in this SRD and others. These math models will include provisions to introduce known error sources.

The sensors to be modeled include:

- o IMU
- o Rate gyros
- o Body accelerometers
- o Radar altimeter
- o Air data probe

- VOR/DME
- ILS and glide slope

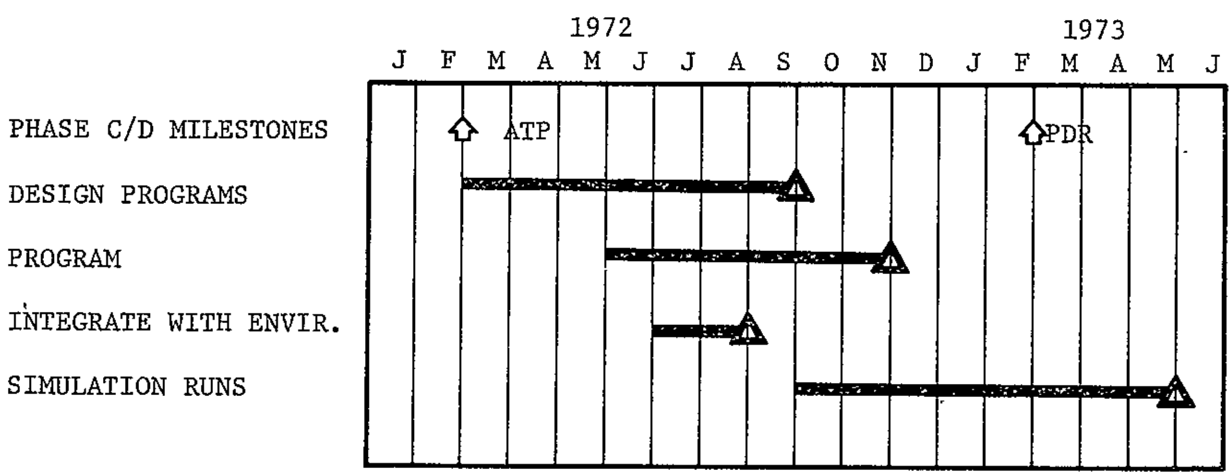
The simulation programs will be used to obtain booster and mated vehicle theoretical closed-loop performance of the guidance, navigation and control subsystems. Input data must be provided to define the initial conditions, error sources and magnitudes, and environmental conditions. The major mission phases to be simulated under this SRD are:

VEHICLE	PHASE
Mated Booster/Orbiter	Launch thru Separation
Booster	Reentry and Transition
	Approach and Landing
	Ferry Mission

The activity covered by this SRD shall be subdivided into discrete problem areas by mission phase for analysis purposes.

FACILITY: A general purpose digital computer with standard peripherals will be required for these simulations.

SCHEDULE: The closed-loop performance must be verified to be adequate prior to final definition of onboard software requirements.



SRD 4.1.2.1

ORBITER FLIGHT CONTROL SYSTEM SIMULATIONS

OBJECTIVE: The objective of this simulation is to evaluate the performance of orbiter flight control system automatic modes of operation. Outputs will consist of:

- Firm definition of flight control system gains coefficients, deadbands, and threshold
- Evaluation of control margins adequacy
- Definition of allowable center of gravity trend
- Definition of attitude control system fuel requirements

JUSTIFICATION: These simulations are required to verify adequacy of the orbiter flight control system concepts prior to their translation into flight software, hardware, and fuel requirements.

DESCRIPTION: Math models of the onboard control system operational modes will be interfaced with the applicable reference environment (Appendix B) and executed to provide performance data. The types of control to be simulated are thrust vector control, (main engine gimbal) reaction jet control, aerodynamic surfaces control, and combinations of the three. Parameters required from the environment simulation (Appendix B) to be used as control signals are shown in the following table for the appropriate mission phase.

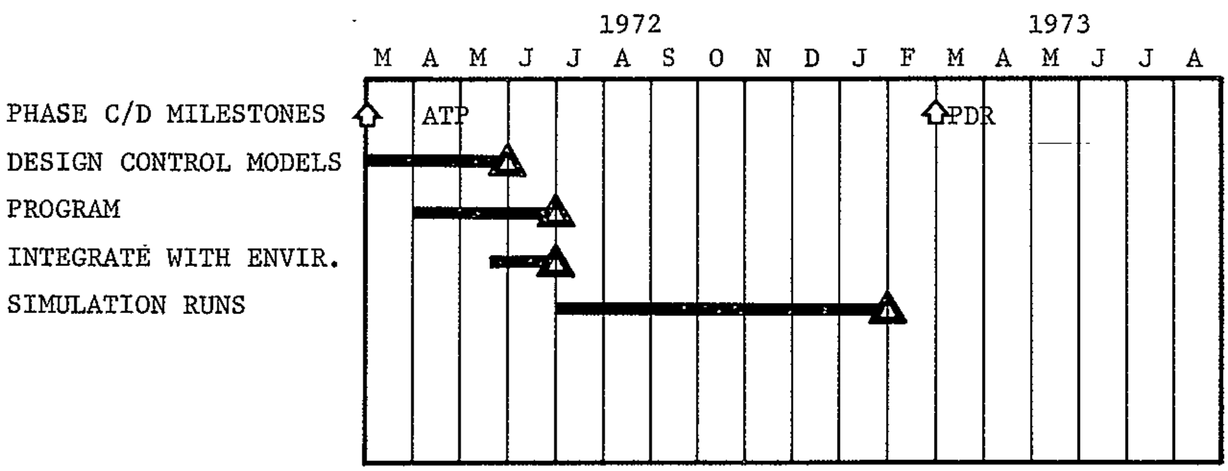
Control Signal \ Mission Phase	Ascent	Entry	Transition	Aerodynamic	On Orbit
Body Angular Rates	X	X	X	X	X
Body Attitude	X	X	X	X	X
Body Accelerations			X	X	
Altitude			X	X	
Range to Runway				X	
Glide Slope Angle				X	
Heading Angle				X	
Bank Angle			X	X	
Angle of Attack			X	X	
True Airspeed			X	X	

The flight control system simulations covered by this SRD will be used to obtain orbiter vehicle theoretical performance figures. That is, the control system and control signals are assumed to be perfect, but the maximum control torques are actual values. Input data required for execution of these simulations fall into two major groups, environment and control system. Data describing the vehicle mass properties, initial state vector, vehicle and control surfaces aerodynamic coefficients, control moments, atmosphere, and winds are required for the environment group. Polynominal coefficients, gains, deadbands, and thresholds must be defined for the control system model.

The flight control system simulation will be written in a scientific language (e.g, Fortran) and should interface with the simulated reference environment software package.

FACILITY: A general purpose digital computer with standard peripherals will be required for executing this simulation.

SCHEDULE: This simulation must be completed prior to generating detailed FCS hardware and software requirements specifications.



SRD 4.1.2.2

ORBITER NAVIGATION SYSTEM SIMULATION

OBJECTIVE: The objective of this simulation is to evaluate the performance of the various types of navigation system configurations for the appropriate mission phase. Outputs will include:

- o Evaluation of sensitivity to errors in initial conditions and navigation sensor inputs
- o Evaluation of integration techniques, step size and error detection
- o Evaluation of update selection criteria
- o Evaluation of ground navigation aid selection criteria

JUSTIFICATION: These simulations are required to verify the capability of the navigation systems to fulfill mission requirements.

DESCRIPTION: The following forms of navigation have been identified for use in the orbiter as indicated:

- o Powered flight navigation - This navigation method consists of real time integration of sensed accelerations and calculated gravitational acceleration. Calculations are performed in an inertial reference frame
- o Coasting navigation - This method of navigation is an integration of computed accelerations, gravitational and aerodynamic. Integration is performed in discrete steps rather than real time (i.e., one step per minute).
- o Autonomous state vector update - Statistical filtering of star measurements is performed to obtain estimates of current position and velocity.
- o Relative motion - This navigation scheme will perform statistical filtering of measurements (e.g., sequential range to target measurements and orbiter body attitude data) to obtain position and velocity of the orbiter with respect to the target.
- o Ground aided navigation - This navigation uses VOR/DME or DME/DME information to locate the vehicle with respect to the navigation aids. Approach mode uses ILS and glide slope information.

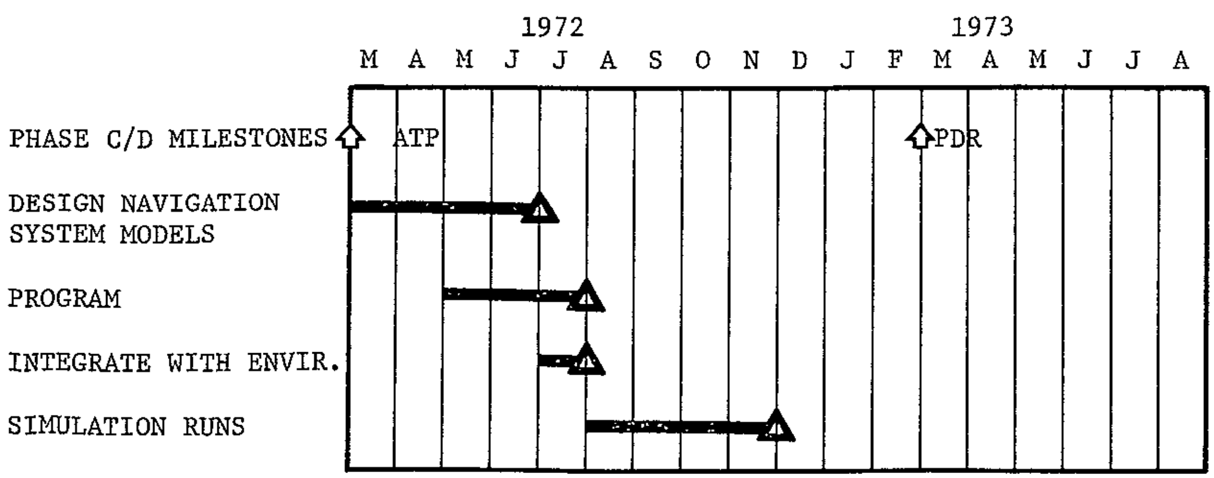
The mission phases that use these navigation methods are shown in the following table:

Navigation Type \ Mission Phase	Ascent	Entry	Transition	Aerodynamic	On Orbit
Power Flight	X	X	X	X	X
Coast	X	X			X
Autonomous State Vector					X
Relative Motion					X
Ground Aided				X	

The simulations covered by this SRD will be used to determine orbiter vehicle navigation subsystem performance based upon perfect sensor data and math models of the onboard navigation systems. These models will be interfaced with the environment program described in Appendix B. In addition to this input, data will be required to define integration intervals, initial navigation state vector, onboard estimates of aerodynamic coefficients, VOR/DME catalog, and ILS data. The simulation will be written in a common scientific language.

FACILITY: A general purpose digital computer with standard peripherals will be required to perform these simulations.

SCHEDULE: These simulations are required to be performed prior to flight software specifications.



SRD 4.1.2.3

ORBITER GUIDANCE & TARGETING SIMULATIONS

OBJECTIVE: The objective of this simulation is to evaluate various targeting and guidance concepts for the different mission phases. Outputs will include:

- o Evaluation of ascent and landing targeting methods
- o Evaluation of performance of the guidance schemes with respect to position, velocity, altitude errors and fuel requirements

JUSTIFICATION: Onboard targeting and guidance techniques must be verified to satisfy mission requirements within specified accuracies, and provide necessary input data for flight software (guidance modules) development.

DESCRIPTION: Simulations to evaluate equations for the ascent and landing targeting problems and guidance equations for ascent, ascent abort, reentry, and terminal area energy management phases are covered by this simulation requirement.

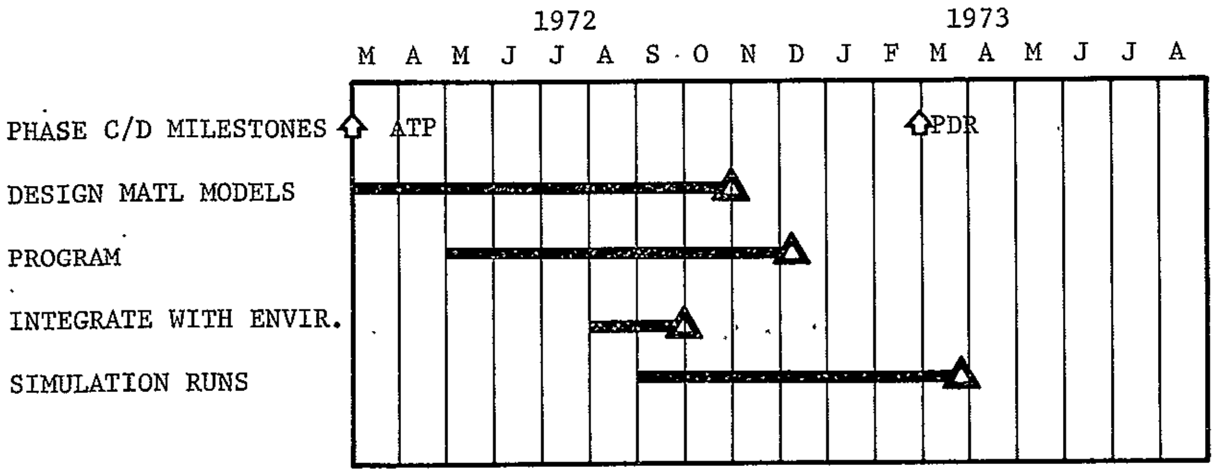
The ascent targeting equations will determine launch time and cutoff conditions based upon rendezvous target ephemeris and desired orbital conditions. The landing targeting problem consists of determining retrograde maneuver, time, and any required intermediate maneuvers to land at a selected site within a given time interval. An alternate method predicts the landing point for a selected retrograde time.

The guidance concepts are evaluated assuming all required translational and attitude maneuvers, and navigations are performed perfectly. Guidance system performance will be specified as errors with respect to the desired condition, fuel penalties, required time, or whatever is applicable to the particular simulation. Uncertainties in the environmental models and the resultant effect on the guidance system performance will be determined by varying the appropriate model input data.

This SRD is intended to cover simulations for the orbiter vehicle guidance systems. These simulation programs will interface with the reference environment program (Appendix B) which requires input data describing vehicle mass properties, initial state vector, aerodynamics, atmosphere, winds, target data, landing site, vehicle propulsion capabilities, and control torques.

FACILITY: A general purpose digital computer with standard peripherals will be required for these simulation programs.

SCHEDULE: These simulations must be completed prior to flight software requirements definitions.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PHASE C/D MILESTONES
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PDR
DESIGN MATL MODELS
PROGRAM
INTEGRATE WITH ENVIR.
SIMULATION RUNS

SRD 4.1.2.4

ORBITER CLOSED-LOOP PERFORMANCE ANALYSIS

OBJECTIVE: The purpose of this task is to evaluate the overall guidance, navigation and control subsystems concept operating as an integrated function in a closed-loop, all-digital, six-degree-of-freedom, rigid-body simulation. Outputs will include:

- o Errors with respect to reference or targeting conditions for various error sources; environmental, flight hardware and flight software
- o Evaluation of closed-loop fuel requirements
- o Definition of flight software requirements

JUSTIFICATION: These simulations are required to verify the adequacy of design of the orbiter guidance, navigation and control subsystems meeting mission objectives.

DESCRIPTION: The computer simulations necessary to conduct closed-loop performance analysis of the orbiter guidance, navigation and control subsystems for all mission phases are covered by this simulation requirements description. Basically these simulations are extensions of appropriate combinations of the Program described in SRD's 4.1.2.1, 4.1.2.2, and 4.1.2.3. Initial investigations using the simulation programs covered by this description shall be directed toward determining that the integrated guidance, navigation and control subsystems will interface satisfactorily. Subsequent investigations shall be conducted to obtain more complete knowledge of the subsystem operating characteristics.

Math models of the guidance, navigation and control subsystems previously written to interface with the reference environment (Appendix B) will be modified to interface with each other. In addition, math models for various onboard guidance and navigation sensors will be developed and included for use in this SRD and others. These math models will include provisions to introduce known error sources. The sensors to be modeled include:

- o IMU
- o Rate gyros
- o Body accelerometers
- o Radar altimeter
- o Air data probe
- o VOR/DME

- o ILS and glide slope
- o Horizon sensor
- o Star tracker

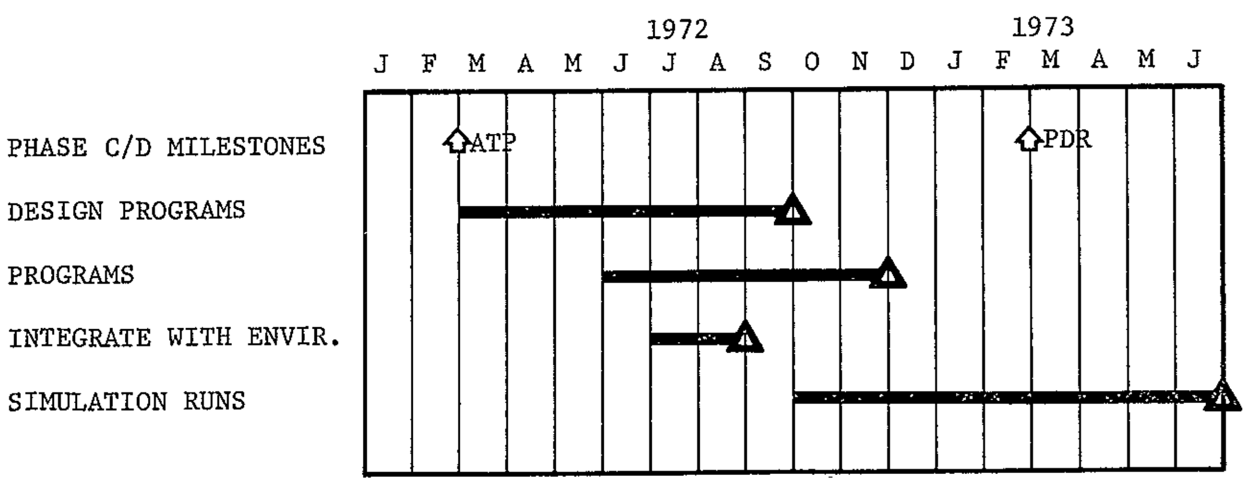
The simulation programs will be used to obtain orbiter vehicle theoretical closed-loop performance of the guidance, navigation and control subsystems. Input data must be provided to define the initial conditions, error sources and magnitudes, and environmental conditions. The major mission phases to be simulated under this SRD are:

- o Ascent-Separation thru Insertion
- o Rendezvous
- o On Orbit
- o Deorbit
- o Reentry and Transition
- o Approach and Landing
- o Ferry Mission

The activity covered by this SRD shall be subdivided into discrete problem areas by mission phase for analysis purposes.

FACILITY: A general purpose digital computer with standard peripherals will be required for these simulations.

SCHEDULE: The closed-loop performance must be verified to be adequate prior to completing definition of the flight software requirements.



SRD 4.2.1.1

BOOSTER LANDING SYSTEM ANALYSIS.

OBJECTIVE: This simulation will be perfomed in order to determine the controllability of the booster by a human pilot after touchdown in the face of ground winds, elastic vehicle vibration due to the touchdown shock, runway surface roughness, landing gear performance, steering sensitivity and steering response lag.

JUSTIFICATION: Lack of control at landing speeds can lead to excessive stress on the vehicle landing gear, tires, structure, and to tipping of the vehicle. A computer simulation of the vehicle motion during roll-out is necessary to verify the landing system design, thus providing a high degree of confidence that major design changes will not be necessary at a later more critical time.

DESCRIPTION: This simulation will require the integration of a number of math models which will provide the means for evaluating landing gear reactions and human pilot controllability for various landing profiles. These math models should include the following:

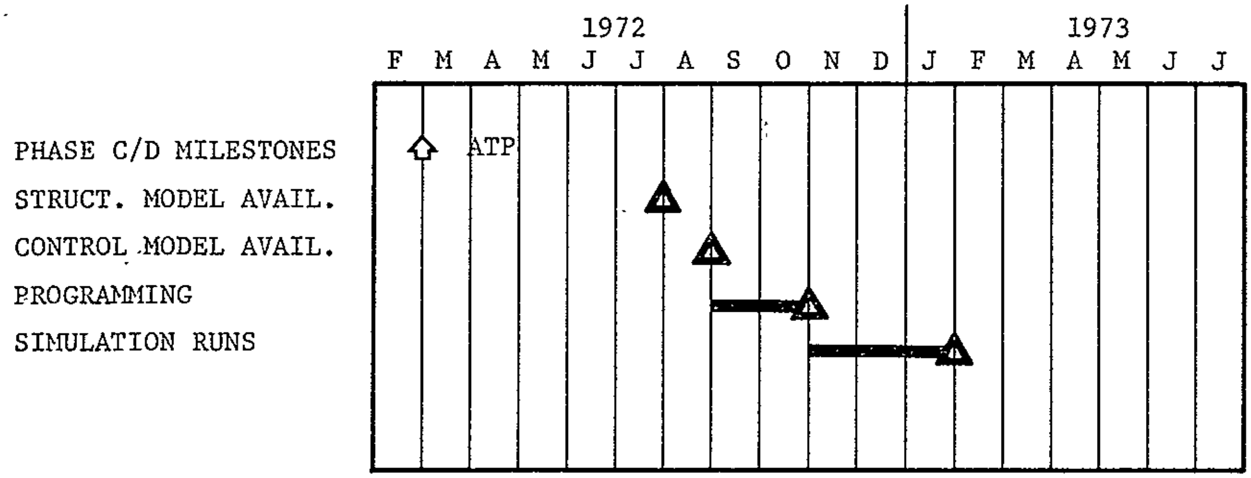
- o a finite-element structural model containing a number of degrees of freedom sufficient to produce the significant vibration modes of the landing configuration and including a detailed model of the landing gear mechanism
- o an aerodynamic model of the vehicle providing the aerodynamic coefficients as function of angle of attack, airspeed, and control surface deflection, and including the ground effect
- o an atmospheric model providing the surface density and acoustic velocity and ground winds
- o models of the responses of the vehicle's control mechanism to pilot controls
- o a human pilot model giving response magnitudes and time lags with respect to computed visual and motion cues

This system of models will be subjected to various ground wind vectors, landing attitudes, and it will compute the resulting vehicle motion. Parametric variation will allow evaluation of the sensitivity of the system to variations in the performance of the human pilot or in the design of vehicle subsystems. In this manner the design of the system will be evaluated to the extent of the model accuracies.

The language used for this task will be Fortran or an equivalent scientific programming language.

FACILITY: This simulation can be performed using a scientific digital computer system such as the CDC 6600 or equivalent.

SCHEDULE: Simulation must be performed early to validate system design and allow release of equipment specifications.



SRD 4.2.2.1

ORBITER LANDING SYSTEM ANALYSIS

OBJECTIVE: This simulation will be performed in order to determine the controllability of the orbiter by a human pilot after touchdown in the face of ground winds, elastic vehicle vibration due to the touchdown shock, runway surface roughness, landing gear performance, steering sensitivity and steering response lag.

JUSTIFICATION: Lack of control at landing speeds can lead to excessive stress on the vehicle landing gear, tires, structure, and to tipping of the vehicle. In order to gain enough design verification to insure that actual vehicle tests will reveal that no major design change is necessary, a computer simulation of the vehicle motion during rollout is required.

DESCRIPTION: This simulation will require the integration of a number of math models:

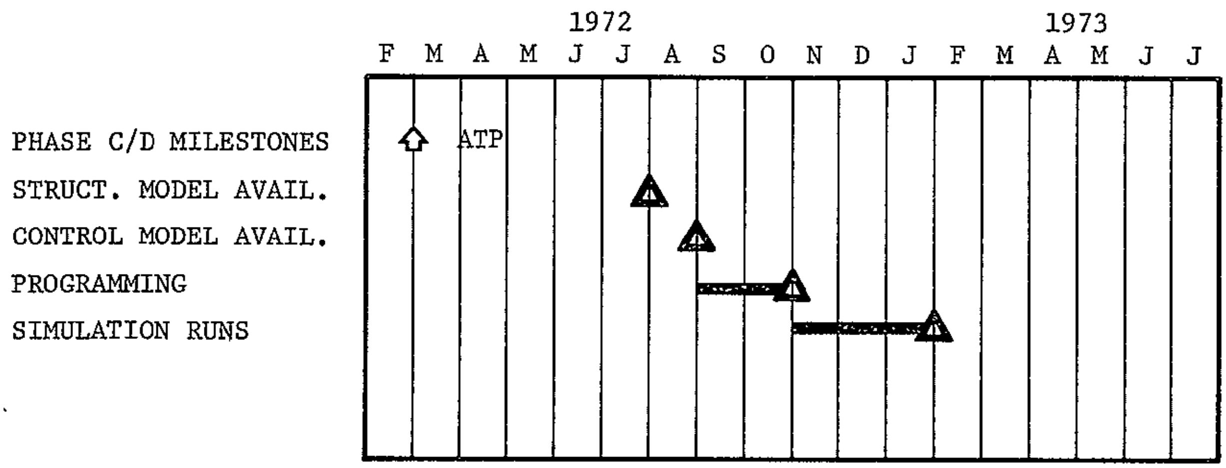
- a finite-element structural model containing a number of degrees of freedom sufficient to produce the significant vibration modes of the landing configuration and including a detailed model of the landing gear mechanism
- an aerodynamic model of the vehicle providing the aerodynamic coefficients as function of angle of attack, airspeed, and control surface deflection, and including the ground effect
- an atmospheric model providing the surface density and acoustic velocity and ground winds
- models of the responses of the vehicle's control mechanism to pilot controls
- a human pilot model giving response magnitudes and time lags with respect to computed visual and motion cues

This system of models will be subjected to various ground wind vectors, landing attitudes, and it will compute the resulting vehicle motion. Parametric variation will allow evaluation of the sensitivity of the system to variations in the performance of the human pilot or in the design of vehicle subsystems. In this manner the design of the system will be evaluated to the extent that the models are accurate.

The language used for this task will be Fortran or an equivalent scientific programming language.

FACILITY: This simulation can be performed using a scientific digital computer system such as the CDC 6600 or equivalent.

SCHEDULE: Simulation must be performed early to validate system design and allow release of equipment specifications.



SRD 4.3.1.1

TRAJECTORY SHAPING FOR TPS WEIGHT MINIMIZATION - BOOSTER

OBJECTIVE: This simulation will yield the reentry flight profile and control law which will allow the use of a Thermal Protection System (TPS) of minimum weight under constraints of maximum axial load factor, minimum cross range, and type of TPS. The program allows a different optimal design for different sets of constraint limits. Outputs will include optimal trajectory time histories of the following:

- o state vector
- o load factor
- o dynamic pressure
- o model number
- o stagnation heating
- o heating rate
- o TPS thickness for acceptable interior temperatures
- o TPS weight
- o minimum weight

JUSTIFICATION: Vehicle system weight minimization on the space shuttle is worth considerable effort and cost in order to maximize allowable payload weight. These computations require computer mechanization due to their complexity and the repetitive nature of optimization studies.

DESCRIPTION: This simulation will involve several steps. The first is to perform a trajectory optimization. This program minimizes a key parameter such as total stangation heat, a function of bank angle and angle of attack, with maximum axial load factor and minimum cross range as constraints. Inputs to the program include:

- o vehicle aerodynamic coefficient
- o mass properties
- o guidance equations
- o initial state vector

The outputs are time histories of state vector, load factor, dynamic pressure, model number and stagnation heating for the optimal trajectory.

The second step involves using the optimal trajectory in a program containing an atmospheric model and heat transfer equations for the materials used and the

properties of aerodynamic flow across the vehicle surfaces to obtain heating rate profiles at selected points on the vehicle surface.

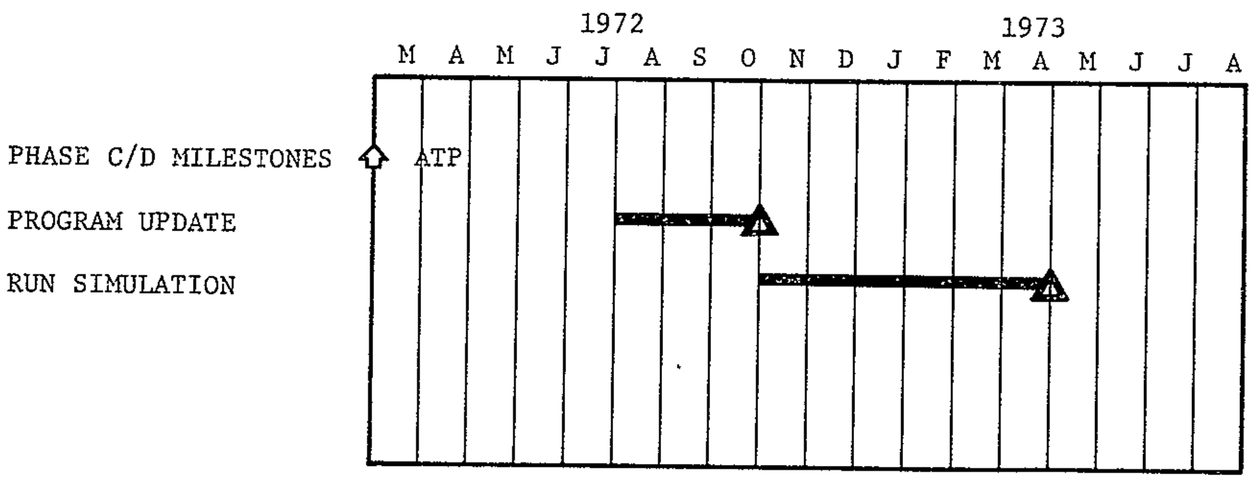
The third step inputs these heating profiles into a program which computes TPS thickness required to limit interior and surface temperatures to acceptable maximum values. From this the program computes the TPS weight.

The process is then iterated changing the optimized parameters and the allowable vehicle control variables to obtain the combination yielding minimum weight.

The programs included here will be written in a scientifically oriented language such as Fortran IV. The trajectory optimization requires about 70K of memory. Due to the piecemeal way the problem is worked, this is all of the memory required. However, if the separate programs are implemented simultaneously on the same run, considerably more capacity would be required.

FACILITY: This problem will be implemented on a scientifically oriented digital computer such as the CDC 6600.

SCHEDULE: This simulation shall be perfomed when trajectory data is available (SRD's 3.1.1.1, 3.1.1.2, 3.1.3.2).



SRD 4.3.2.1

TRAJECTORY SHAPING FOR TPS WEIGHT MINIMIZATION - ORBITER

OBJECTIVE: This simulation will yield the reentry flight profile and control law which will allow the use of a Thermal Protection System (TPS) minimum weight under constraints of maximum axial load factor, minimum cross range, and type of TPS. The program allows a different optimal design for different sets of constraint limits.

JUSTIFICATION: Weight minimization on the space shuttle is worth considerable effort and cost in order to maximize allowable payload weight. These computations require computer mechanization due to their complexity and the repetitive nature of optimization studies.

DESCRIPTION: This simulation will involve several steps. The first is to perform a trajectory optimization. This program minimizes a key parameter such as total stagnation heat function of bank angle and angle of attack with maximum axial load factor and minimum cross range as constraints. Inputs to the program include vehicle aerodynamic coefficients, mass properties, guidance equations and initial state vector. The outputs are time histories of state vector, load factor, dynamic pressure, model number and stagnation heating for the optimal trajectory.

The second step involves using the optimal trajectory in a program containing an atmospheric model and heat transfer equations for the materials used and the properties of aerodynamic flow across the vehicle surfaces to obtain heating rate profiles at selected points on the vehicle surface.

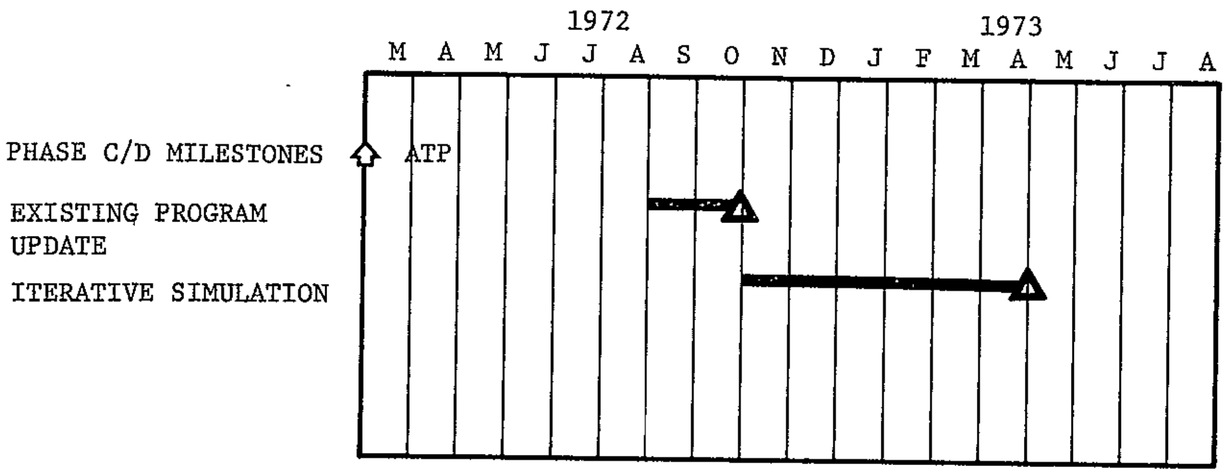
The third step inputs these heating profiles into a program which computes TPS thickness required to limit interior and surface temperatures to acceptable maximum values. From this the program computes the TPS weight.

The process is then iterated changing the optimized parameters and the allowable vehicle control variables to obtain the combination yielding minimum weight.

The programs included here will be written in a scientifically oriented language such as Fortran IV. The trajectory optimization requires about 70K of memory. Due to the piecemeal way the problem is worked, this is all of the memory required. However, if the separate programs are implemented simultaneously on the same run, considerably more capacity would be required.

FACILITY: This problem will be implemented on a scientifically oriented digital computer such as the CDC 6600.

SCHEDULE: This simulation shall be performed when trajectory data is available (SRD's 3.1.2.1, 3.1.2.3, 3.1.2.4).



SRD 5.1.1.1.1

BOOSTER MAIN PROPULSION THRUST BUILDUP

OBJECTIVE: The objective of this simulation is to provide a tool for determining the optimum start-up time and dynamic amplification factors which can be utilized in establishing the optimum feedline diameter. Outputs from this simulation should include:

- o pump inlet pressure
- o pressure drop versus thrust
- o thrust versus propellant consumption in terms of individual as well as total thrust

JUSTIFICATION: To gather the information required to be obtained by this simulation by other means such as utilizing actual hardware would delay the design and be extremely costly to perform. The only way to assure the optimum diameter for the feedline and that there is sufficient NPSP at the pump inlet during start is through this type simulation. Proper use of this program should provide considerable savings in hardware and propellant weight.

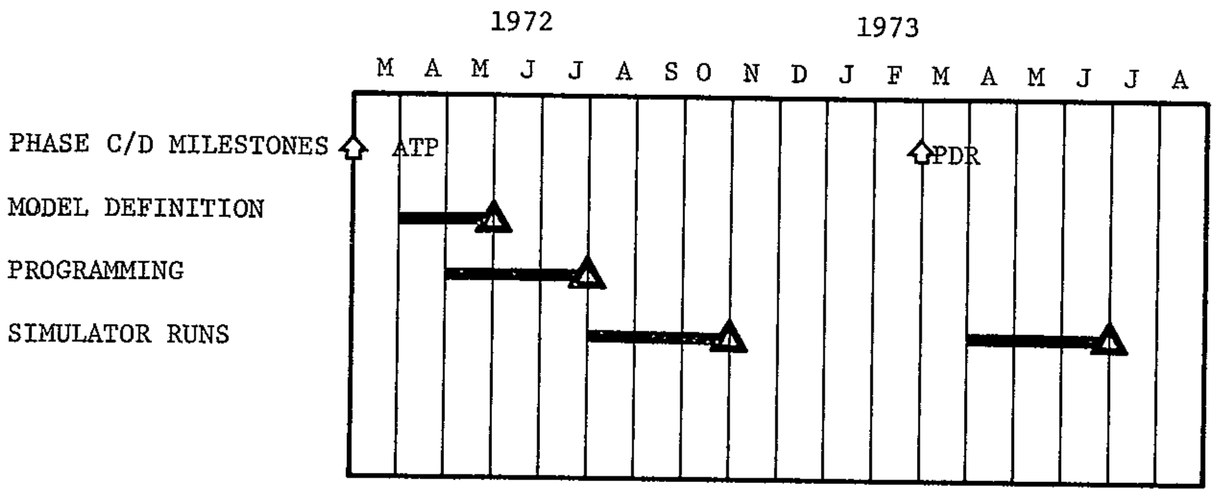
DESCRIPTION: This digital computer simulation will require math modeling of thrust versus startup time with various combinations of engines and starting intervals. Some of the inputs to the simulation should be:

- o feedline design factors
- o flow rates
- o propellant consumption

Data derived from this simulation will be utilized in the dynamic flow and pressurization system simulation (SRD 5.1.1.1.4).

FACILITY: A general purpose digital computer can be used to run this simulation.

SCHEDULE: This simulation should be run prior to the pressuriation system and feedline flow characteristics simulations.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MODEL DEFINITION
PROGRAMMING
SIMULATOR RUNS

SRD 5.1.1.1.2

BOOSTER PROPULSION PNEUMATIC CONTROL SYSTEM

OBJECTIVE: The objective of this simulation is to provide a computer model of the pneumatic control system which can be exercised to check the power control for the propulsion system components under various phases of propulsion control. Control performance will be evaluated by analyzing the following outputs:

- o helium flow rates
- o total mass of helium required
- o pressure changes
- o temperature changes

JUSTIFICATION: To allow checking of system performance under various engine demands and system demands in a timely and economical manner requires the use of a computer program. A significant weight savings can result from this simulation through optimizing the loading pressure.

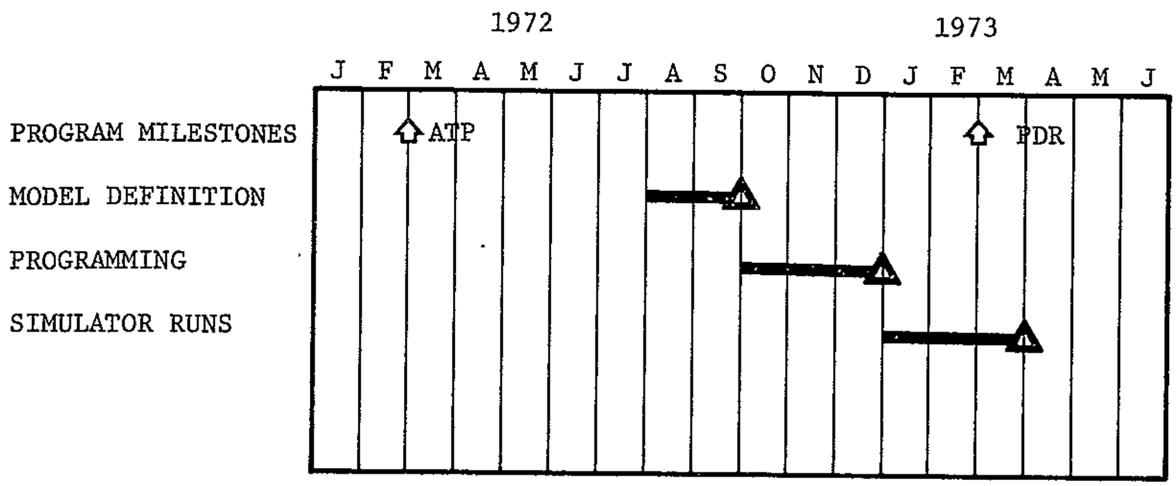
The hardware and testing facilities required to perform actual physical tests on such a system would be prohibitive and would not fit the schedule.

DESCRIPTION: This simulation will be performed by a digital computer program. Math models of the pneumatic system should contain simulations for the several components of the system including a common supply with separate pressure regulation for the engine and stage systems. The program should cover operation of power control from pre-liftoff to vehicle landing under various stages of pneumatic operation such as:

- o low or no flow
- o instantaneous flow due to actuation of valves
- o engine start
- o burn
- o cutoff transients
- o ground and inflight purges

FACILITY: This simulation can be run on a general purpose digital computer.

SCHEDULE: This simulation should be performed after pressurization system, and feedline flow characteristics have determined pneumatic system requirements.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SRD 5.1.1.1.3

BOOSTER PROPULSION PROPELLANT DUMPING

OBJECTIVE: The purpose of this simulation is to establish propellant dumping capabilities and limitations for voiding the main propellant tankage of unburned liquid residual.

Some of the outputs that will be obtained in establishing these limitations will be:

- o dump rates through engines and dedicated system
- o dumping time
- o thrust during dump
- o total impulse of main engine during dump
- o specific impulse of the main engine during dump

JUSTIFICATION: This simulation must be performed to determine the effects of backsurge which occurs during cutoff transient and to determine the dumping capabilities early in the design. Actual test or performance of this function would be very difficult and would not be able to be performed until the system fabrications were almost complete or a special test system fabricated. Costs of special test systems and the additional time required can not be tolerated. Optimization of the dumping capabilities can reduce the design landing weight.

DESCRIPTION: This will be an all digital simulation. Math models will be utilized to determine dump rates through the engines and system and to determine timing requirements. Dump capabilities are dependent upon proper timing. This program should establish the following times:

- o time from cutoff to vehicle dump valve open
- o time to settle liquid, considering influence of drag force and pressure differential
- o time required to dump residual liquids

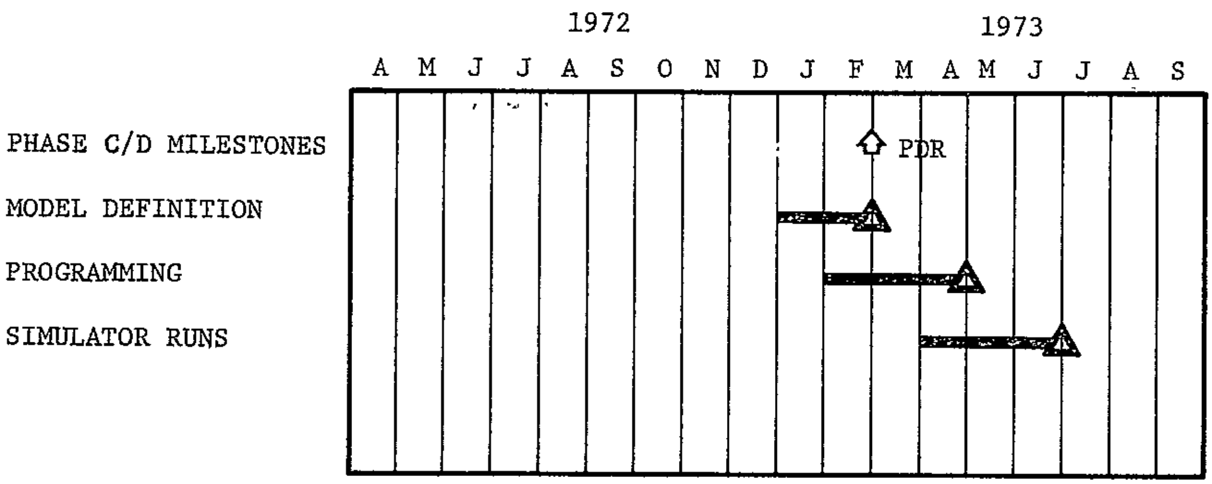
Other considerations of this program should be propellant settling through addition of baffles and through the use of external thrust.

Some of the input parameters should be:

- o dump valve sizes
- o drain valve sizes
- o engine performance data
- o drag force on liquid propellant

FACILITY: This simulation can be run on a general purpose digital computer.

SCHEDULE: This simulation can be performed after the propellant system and engine performance simulations.



SRD 5.1.1.1.4

BOOSTER FEED SYSTEM/ENGINE INTERACTION

OBJECTIVE: The purpose for this simulation is to provide a tool for establishing propellant tank pressurization and venting histories and to determine inertial and friction losses under various system control conditions and environmental conditions including maximum and minimum demand. Outputs from this program should include:

- inertial pressure drop and friction pressure drop as a function of start transient and flow rate
- system flow rate
- pump inlet pressure profiles
- surge pressure at engine cutoff
- wave travel time through pipe segments
- values of head and flow
- chamber pressure
- turbine speed
- mass outflow from surge tanks

JUSTIFICATION: The capability to analyze the problems associated with propulsion pressurization systems, including the transient flow of cryogen, is necessary for designing efficient, reliable, and safe fuel systems. This can be done most timely and economically with the aid of a computer programmed simulation, far in advance of fabricating and testing hardware. Obtaining of maximum weight savings and high reliability with an associated cost savings should be the results of this simulation.

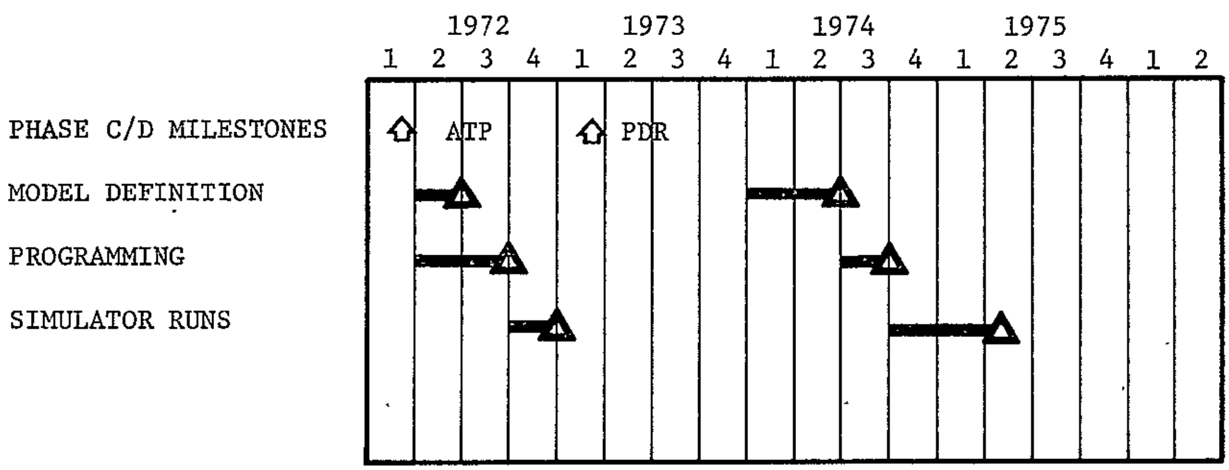
DESCRIPTION: This simulation should be performed through the use of a scientific digital computer. Several existing programs could be utilized with modifications to provide a dynamic flow simulation for the main propulsion system. The math model for the pressurization system should include propellant tank, pump, and all line segments between the tank and pump inlet.

One of the phenomena that should be considered is water hammer effects. The program should be exercised to establish control of tank pressuries including protection overpressure. Booster vent and relief system should be exercised for various operating conditions during ground hold, during burn and during reentry. Redundant valving and actuation methods for fail operational, fail safe requirements should be included as well as regulation of pressure in primary and secondary vent system. Inputs should include:

- o propellant properties data
- o propellant tank description data
- o pressure drop
- o feedline data
- o compound datum height
- o flow rate
- o vehicle acceleration

FACILITY: This simulation can be run on a scientific digital computer.

SCHEDULE: This simulation should be performed prior to the engine performance simulation, and integrated with engine performance simulation later in the program.



SRD 5.1.1.1.5

BOOSTER PROPELLANT TANK DRAINAGE MODEL

OBJECTIVE: This simulation will determine the amount of fuel unavailable for use due to incomplete draining of the propellant tanks prior to introduction of pressurant gas in the outflow line.

JUSTIFICATION: Unavailable propellant must be known in order to allow for it in determining the total amount of propellant required for a given mission. The quantities of fuel and oxidizer unavailable must also be minimized since it contributes to gross liftoff weight. This simulation will function as a design tool in an effort to reduce residual propellant.

There is no alternative to a scaled physical model in the solution of this problem due to the fact that mathematical descriptions of the drainage process are not presently known.

DESCRIPTION: For this simulation, a number of physical models of the propellant tanks will be built. These models will exhibit drainage characteristics similar to candidate designs of the actual tanks. Volumetric flowrate, residual volume, characteristic length (e.g., outflow pipe diameter), and slosh frequencies for the model using water will bear a known relationship to those in the real system. Dynamically similar results will be obtained if outlet geometry is similar (though scaled down) and if also the outlet Froude numbers are equal for both the models and their real-world counterparts. The Froude number is given by:

$$Fr = \frac{V^2}{ad}$$

where V is the average velocity across the outlet given by:

$$V = \frac{Q}{A}$$

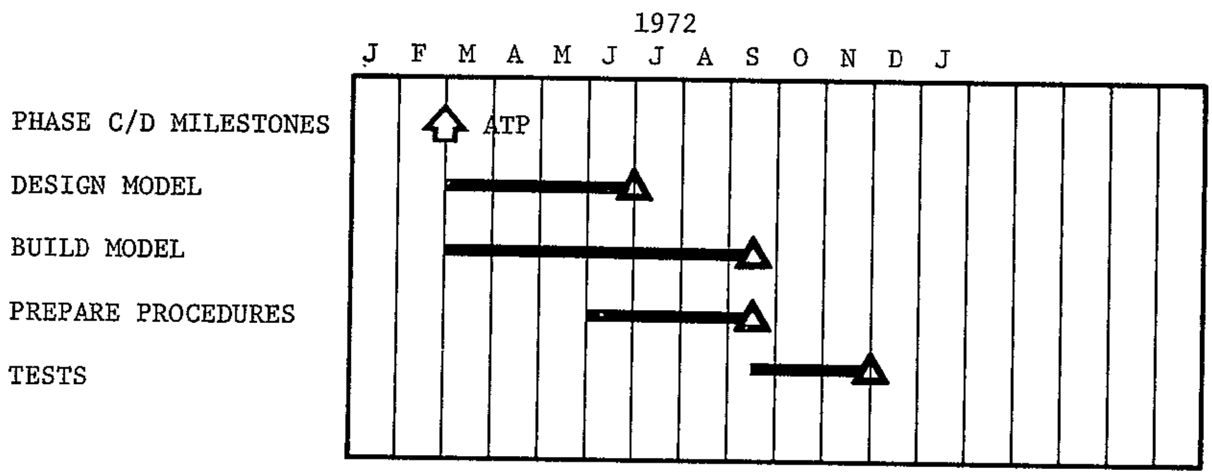
where Q is the volumetric flow and A the cross-sectional area of the outlet, a is the acceleration of the fluid relative to the outlet structure (one "g" for a stationary tank on Earth's surface) and d is the outlet diameter. This scaling allows the use of water as the working fluid in much smaller structures than the tanks modeled.

The models will be subject to drainage tests in which flowrate is recorded as a function of time and high speed motion pictures of the liquid surface motion at the outlet are taken. The liquid volume remaining when mixed-phase fluid enters the outlet is the residual volume to be minimized. This can be calculated from

readings taken on the graduated tank wall and knowledge of the fluid circuit geometry.

FACILITY: The equipment required for this simulation in addition to the tank models and source of working fluid will be flow meters, manometers, and high speed motion picture camera, and a strip chart recorder.

SCHEDULE: Simulation should be run during early phase of fuel delivery system development as a design aid.



SRD 5.1.1.2.1

ORBITER MAIN PROPULSION FEED SYSTEM/ENGINE INTERACTION

OBJECTIVE: These simulations will provide information from which design specification requirements will be established. They will also provide system design verification when component models are refined and integrated. The comprehensive propulsion model developed herein will provide the capability to investigate the structural/propulsion stability problem (POGO) discussed in SRD 3.2.2.3.

JUSTIFICATION: Realistic prediction of the effects of parameter variations are required to specify component requirements and can best be obtained through computer simulation due to its convenience, accuracy, and versatility. The complex interaction of subsystem models must be determined to verify design adequacy. Simulation provides an economical and timely tool for performing this function.

DESCRIPTION: This task is a sequence of subtasks which will span the entire design phase of the shuttle project.

Early Work - In the early phases simple subsystem models will be developed for the purpose of establishing component specification requirements. These models will ignore subtle or high order effects. The subsystems so modeled will include the autogenous engine bleed propellant tank pressurization and vent system, and feed, fill, and drain system. These simulations will be refined as vendor data on actual hardware is made available and eventually will produce high fidelity subsystem models. The system components involved will include valves, feed lines, tankage, flex lines, and bellows. The component parameters of importance will be valve actuation time histories, line and component resistance to flow, instabilities in flex lines and bellows. A problem that will be investigated in these early studies is "water hammer". This problem occurs in a liquid system when a sudden pressure change due to rapid operation of a valve initiates shock waves that overstress components. The effects of system transients resulting from venting and dumping will be investigated in order to size these systems.

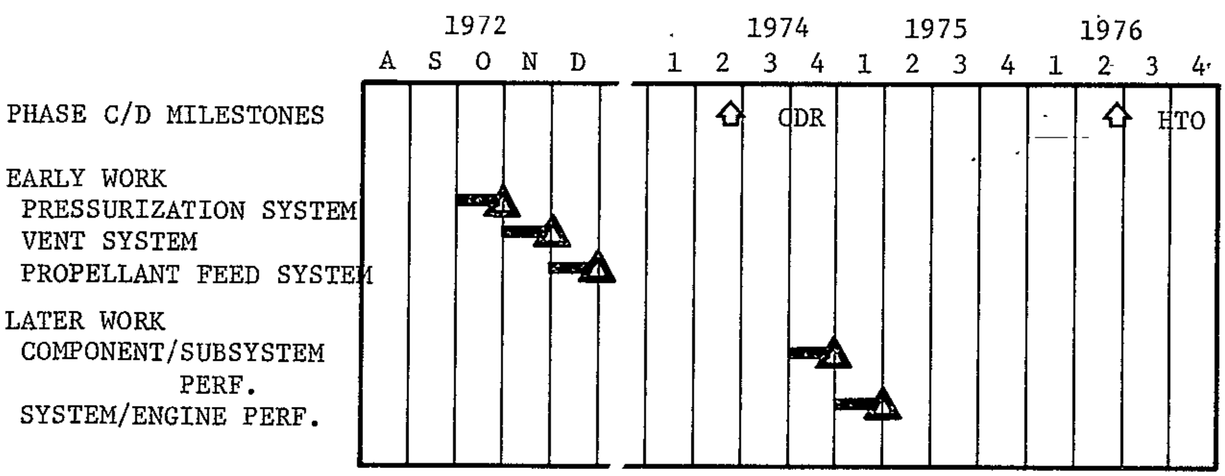
Later Work - The engine manufacturers will construct a mathematical model of the engine composed of an integrated system of engine component models. This model will compute the engine's thrust response to pressures and temperatures at its oxidizer and fuel inlets and to commands to its controller electronics as functions of internal engine component parameters describing turbopump performance,

thrust chamber geometry and other performance-sensitive engine parameters whose precise value is uncertain. The model will also compute the pressure and temperature response at the engine autogenous pressurization bleed ports.

With the models of the engine and feed system integrated, a design verification simulation can be performed to verify the compatibility of the subsystems, one with another. Due to the lateness of this effort, its purpose is not to uncover the need for major design changes. Design refinements with minor impact will be made if possible. The model thus constructed will be used to make flight performance predictions to determine the optimum manner in which the system should be operated. It will be used to work the "POGO" problem discussed in SRD 3.2.2.3.

FACILITY: A general-purpose digital computer with standard peripherals will be adequate for this task.

SCHEDULE: Early simulations shall be run to aid in component design later simulations are performed when engine math model is available to evaluate feedline/ engine interaction.



SRD 5.1.1.2.2

ORBITER MAIN PROPULSION PNEUMATIC CONTROL SYSTEM

OBJECTIVE: This simulation will investigate the pneumatic equivalent of the "water hammer" effect in hydraulic systems for the pneumatic control system. It will also aid in determining sizing requirements for system components and in observing the system's speed of response to input commands.

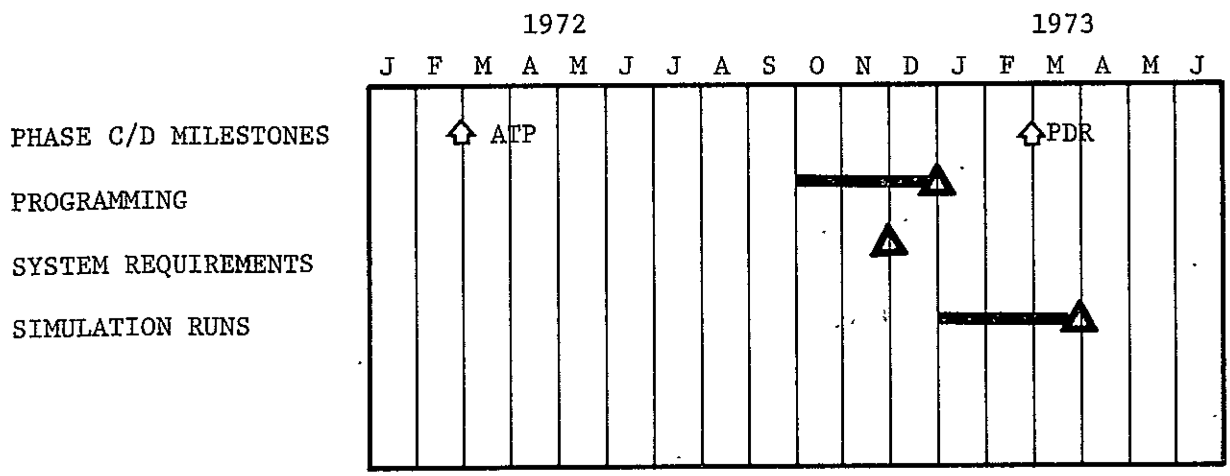
JUSTIFICATION: The "water hammer" effect can result in excessive stress on system components. Costly redesign efforts are required if the problem is discovered after the hardware has been procured. Therefore lowest system cost dictates that simulation be used as a design tool early in Phase C to properly size and configure the components of the system. Changes to system environment or component characteristics can then be put into the computer model to assess their effects on system performance.

DESCRIPTION: The "water hammer" effect is present in fluid systems experiencing sudden changes in boundary conditions. For example, when a valve is turned off, a shock wave will travel through the system, bounding off discontinuities within the system. This process is described by fluid flow partial differential equations and boundary conditions for each component of the system. These components are modeled and integrated such that one component's output boundary conditions forms the input boundary conditions of adjacent components.

Standard programs are available for use in simulating system operation by constructing a series of lumped models to represent the distributed fluid line. These programs provide models for friction points, T-joints, cross joints, turbo Pumps, injectors, valves, cap ends, lines and other components. From this model of the pneumatic control system, the response of the system to sudden inputs can be computed. The magnitude of the resulting pressure shocks will indicate to what extent components are stressed. Changes can be made to valve closing times or accumulator or plenum sizes and the system may then be re-evaluated.

FACILITY: This simulation will require a large-scale scientific, digital computer such as the CDC 6600.

SCHEDULE: This simulation will be run in the early stages of Phase C and may be revised and rerun if design changes are made which could significantly affect system dynamic response.


1972
1973
J F M A M J J A S O N D J F M A M J
PHASE C/D MILESTONES
ATP
PDR
PROGRAMMING
SYSTEM REQUIREMENTS
SIMULATION RUNS

SRD 5.1.1.2.3

ORBITER PROPELLANT TANK DRAINAGE MODEL

OBJECTIVE: This simulation will determine the amount of fuel unavailable for use due to incomplete draining of the propellant tanks prior to introduction of pressurant gas in the outflow line.

JUSTIFICATION: Unavailable propellant must be known in order to allow for it in determining the total amount of propellant required for a given mission. The quantities of fuel and oxidizer unavailable must also be minimized since it contributes to gross liftoff weight. This simulation will function as a design tool in an effort to reduce residual propellant.

There is no alternative to a scaled physical model in the solution of this problem due to the fact that mathematical descriptions of the drainage process are not presently known.

DESCRIPTION: For this simulation, a number of physical models of the propellant tanks will be built. These models will exhibit drainage characteristics similar to candidate designs of the actual tanks. Volumetric flowrate, residual volume, characteristic length (e.g., outflow pipe diameter), and slosh frequencies for the model using water will bear a known relationship to those in the real system. Dynamically similar results will be obtained if outlet geometry is similar (though scaled down) and if also the outlet Froude numbers are equal for both the models and their real-world counterparts. The Froude number is given by:

$$Fr = \frac{V^2}{ad}$$

where V is the average velocity across the outlet given by:

$$V = \frac{Q}{A}$$

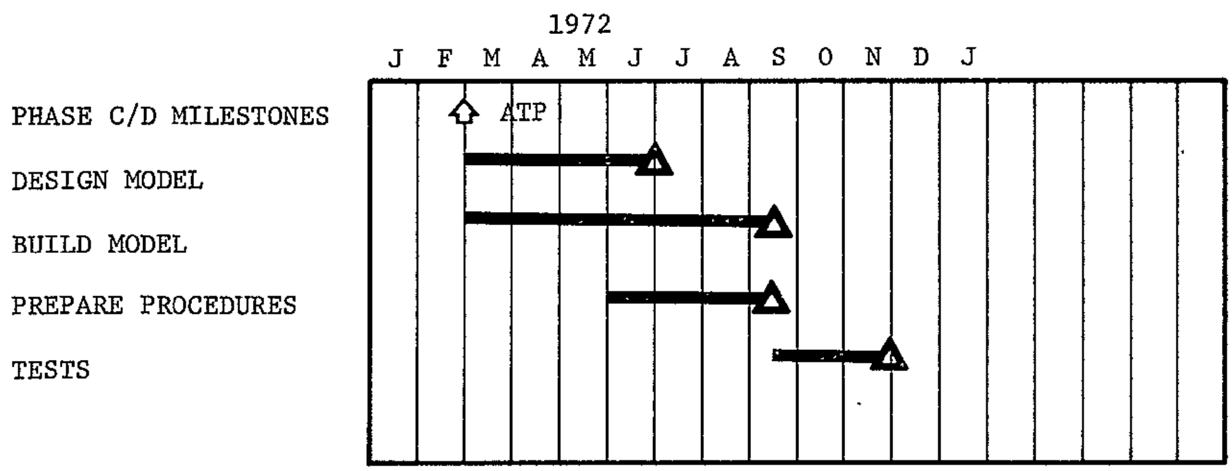
where Q is the volumetric flow and A is the cross-sectional area of the outlet, a is the acceleration of the fluid relative to the outlet structure (one "g" for a stationary tank on Earth's surface) and d is the outlet diameter. This scaling allows the use of water as the working fluid in much smaller structures than the tanks modeled.

The models will be subject to drainage tests in which flowrate is recorded as a function of time and high speed motion pictures of the liquid surface motion at the outlet are taken. The liquid volume remaining when mixed-phase fluid enters the outlet is the residual volume to be minimized. This can be calculated

from readings taken on the graduated tank wall and knowledge of the fluid circuit geometry.

FACILITY: The equipment required for this simulation in addition to the tank models and source of working fluid will be flow meters, manometers, a high speed motion picture camera, and a strip chart recorder.

SCHEDULE: Simulation shall be run during early phase of fuel delivery system development as a design aid.



SRD 5.1.2.1.1

BOOSTER ACPS ENGINE/FUEL DELIVERY SYSTEM SIMULATION

OBJECTIVE: The purpose of this task is to evaluate the compatibility of the ACPS propellant delivery system with the system of thrusters through simulation of the pressure, temperature, and flow of the propellant gases through the system's components and plumbing. The simulation will establish propellant conditioning performance requirements and allowable plumbing losses.

JUSTIFICATION: The feedline heat and pressure losses will affect the performance of the ACPS engines. This effect can lead to deviations of actual torque from commanded torque and excessive fuel consumption. The former effect causes undesired translational forces when pure couple is desired, necessitating additional thruster activity to achieve the attitude desired. This simulation will aid the design of the system to minimize and allow for these errors. The complexity of the system dictates that computer simulation be employed rather than direct calculation. The requirement for problem solutions early in the design phase rules out the use of hardware mockups for this purpose.

DESCRIPTION: This simulation will determine the transient behavior of the ACPS for expected mission conditions by integrating a system of math models of the components of the system. The components modeled will be:

- o Lines
- o Valves
- o Orifices
- o Regulators
- o Thrustors
- o Accumulators

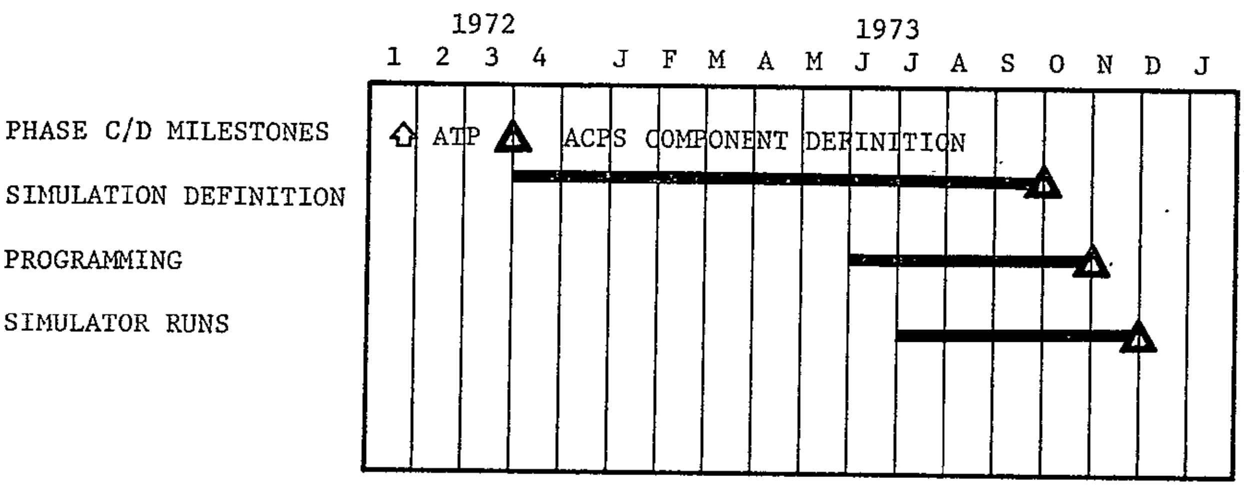
The simulated system will accurately reflect the actual system's configuration. Line lengths and diameters and component locations will be accurately simulated. The thruster combustion and performance parameters will be calculated assuming an equilibrium combustion process. This assumption, while ideal, does not strongly differ from the actual process, and it permits use of tractable equations.

The program will produce time histories of temperature, pressure, and flow at any desired location within the system. Also specific impulse, total impulse, mixture rates, and thruster chamber temperature will be computed in order to evaluate engine performance.

This program will reveal sensitivities of ACPS performance to component parameter value mix and subsystem parameters such as oxygen or hydrogen accumulator temperature and pressure. It will give actual versus commanded torque and forces on the vehicle. It will reveal any thruster/feedline incompatibilities and point to the design changes necessary to correct problems.

FACILITY: This simulation can be run on any large scientifically oriented digital computer such as the CDC 6600.

SCHEDULE: Simulation should be run later in ACPS development programs, on receipt of design data from component vendors, to perform subsystem simulation prior to design freeze.



SRD 5.1.2.1.2

BOOSTER ACPS FUEL CONDITIONER/FEED SYSTEM INTERACTION

OBJECTIVE: This simulation will determine the effects of gas generator start and stop operation on the temperature and pressure of the gases at the regulator output. By means of this simulation

- o the accumulator can be sized,
- o switch pressures for optimum gas generator cycling can be established,
- o the effects on gas conditioning of component parameter value variations can be assured, and
- o transient behavior of the propellant conditioner can be evaluated.

JUSTIFICATION: The transient response of the conditioner assembly determines the required ratio of switching pressure to minimum operating pressure. This ratio plus the blowdown ratio (maximum pressure to switching pressure) determines the accumulator weight and number of conditioner cycles required. Thus system weight and reliability are dependent on the results of this simulation. Due to the complexity of the system and the early need for the data, simulation is the best means of acquiring this information.

DESCRIPTION: This simulation will require math models of:

- o Gas Generator
- o Turbine/Pump
- o Heat Exchanger
- o Accumulator
- o Valves
- o Plumbing Lines

These will be integrated into models for both the oxygen and hydrogen conditioner systems. The simulated systems will produce time histories of pressure, temperature, and flow at points of interest in the conditioner assembly. The exact start-up behavior can be predicted.

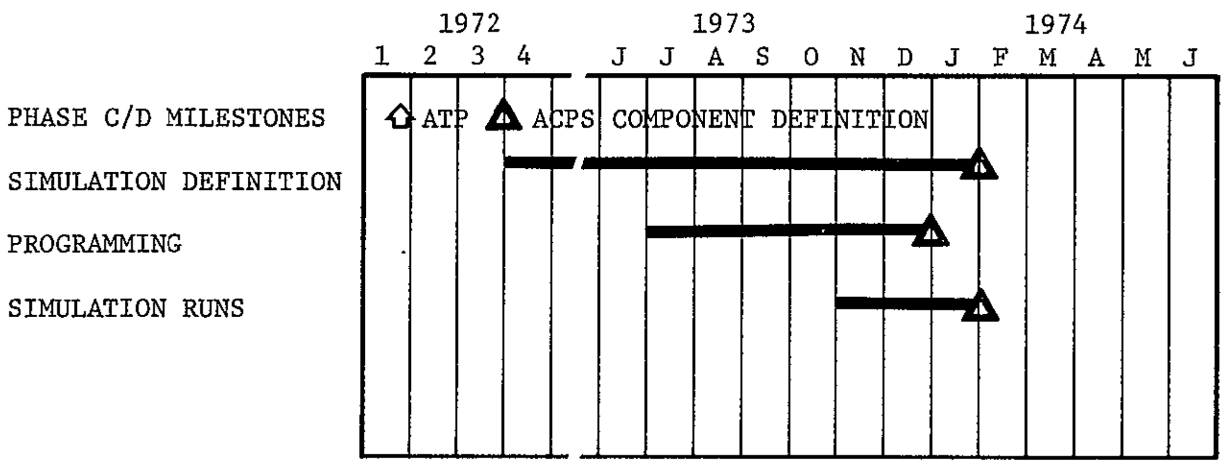
The model for the gas generator will give output pressure and temperature as a function of output flow demand by the turbine, input oxygen and hydrogen pressures and temperatures, and pressure and thermal losses. The turbopump math models will include turbine pressure and temperature drops and rotating assembly equations of motion. The heat exchanger model will involve thermodynamic energy balance relationships, and that of the accumulator will involve conservation of

mass and energy equations. The lines and valves will be modeled in sufficient detail to include their effects on speed of response and plumbing losses.

The simulation program will use a scientific language such as Fortran IV.

FACILITY: Any scientifically oriented digital computer (e.g., CDC 6600) can handle the task adequately.

SCHEDULE: Simulation is run as a design aid prior to final subsystem definition.



SRD 5.1.2.2.1

ORBITER ACPS FUEL CONDITIONER/FEED SYSTEM INTERACTION

OBJECTIVE: This simulation will determine the effects of gas generator start and stop operation on the temperature and pressure of the gases at the regulator output. By means of this simulation

- the accumulator can be sized,
- switch pressures for optimum gas generator cycling can be established,
- the effects on gas conditioning of component parameter value variations can be assured, and
- transient behavior of the propellant conditioner can be evaluated.

This simulation will be performed on both Orbiter and Booster attitude control propulsion systems.

JUSTIFICATION: The transient response of the conditioner assembly determines the required ratio of switching pressure to minimum operating pressure. This ratio plus the blowdown ratio (maximum pressure to switching pressure) determines the accumulator weight and number of conditioner cycles required. Thus system weight and reliability are dependent on the results of this simulation. Due to the complexity of the system and the early need for the data, simulation is the best means of acquiring this information.

DESCRIPTION: This simulation will require math models of:

- Gas Generator
- Turbine/Pump
- Heat Exchanger
- Accumulator
- Valves
- Plumbing Lines.

These will be integrated into models for both the oxygen and hydrogen conditioner systems. The simulated systems will produce time histories of pressure, temperature, and flow at points of interest in the conditioner assembly. The exact start-up behavior can be predicted.

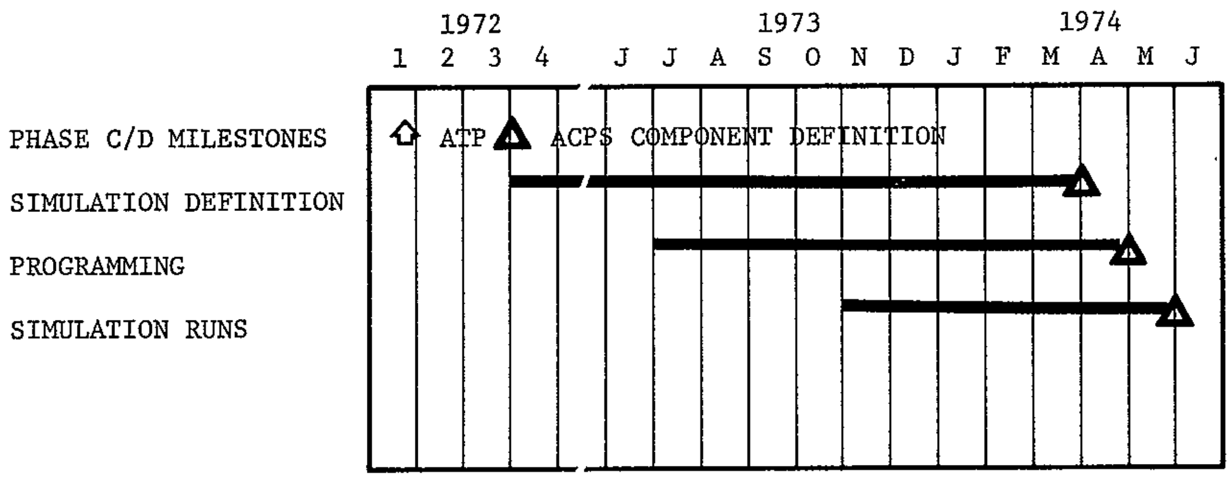
The model for the gas generator will give output pressure and temperature as a function of output flow demand by the turbine, input oxygen and hydrogen pressures and temperatures, and pressure and thermal losses. The turbopump math models will include turbine pressure and temperature drops and rotating assembly equations of motion. The heat exchanger model will involve thermodynamic energy balance

relationships, and that of the accumulator will involve conservation of mass and energy equations. The lines and valves will be modeled in sufficient detail to include their effects on speed of response and plumbing losses.

The simulation program will use a scientific language such as Fortran IV.

FACILITY: Any scientifically oriented digital computer (e.g., DCD 6600) can handle the task adequately.

SCHEDULE: Simulation is run as a design aid prior to final subsystem definition.



SRD 5.1.2.2.2

ORBITER ACPS ENGINE/FUEL DELIVERY SYSTEM SIMULATION

OBJECTIVE: The purpose of this task is to evaluate the compatibility of the ACPS propellant delivery system with the system of thrusters through simulation of the pressure, temperature, and flow of the propellant gases through the system's components and plumbing. The simulation will establish propellant conditioning performance requirements and allowable plumbing losses.

JUSTIFICATION: The feedline heat and pressure losses will affect the performance of the ACPS engines. This effect can lead to deviations of actual torque from commanded torque and excessive fuel consumption. The former effect causes undesired translational forces when pure couple is desired, necessitating additional thruster activity to achieve the attitude desired. This simulation will aid the design of the system to minimize and allow for these errors. The complexity of the system dictates that computer simulation be employed rather than direct calculation. The requirement for problem solutions early in the design phase rules out the use of hardware mockups for this purpose.

DESCRIPTION: This simulation will determine the transient behavior of the ACPS for expected mission conditions by integrating a system of math models of the components of the system. The components modeled will be:

- o Lines
- o Valves
- o Orifices
- o Regulators
- o Thrustors
- o Accumulators

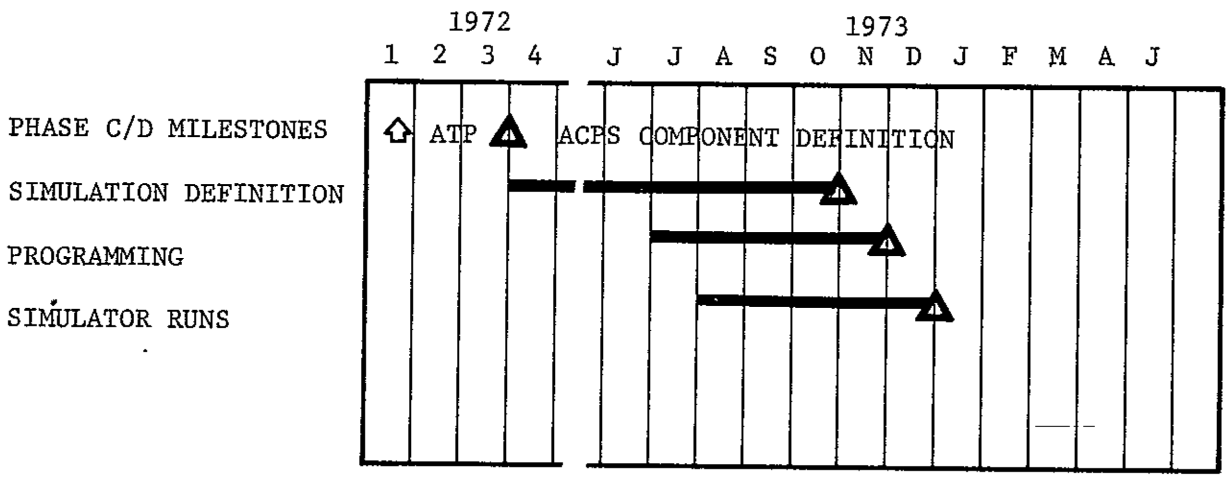
The simulated system will accurately reflect the actual system's configuration. Line lengths and diameters and component locations will be accurately simulated. The thruster combustion and performance parameters will be calculated assuming an equilibrium combustion process. This assumption, while ideal, does not strongly differ from the actual process, and it permits use of tractable equations.

The program will produce time histories of temperature, pressure, and flow at any desired location within the system. Also specific impulse, total impulse, mixture rates, and thruster chamber temperature will be computed in order to evaluate engine performance.

This program will reveal sensitivities of ACPS performance to component parameter value mix and subsystem parameters such as oxygen or hydrogen accumulator temperature and pressure. It will give actual versus commanded torque and forces on the vehicle. It will reveal any thruster/feedline incompatibilities and point to the design changes necessary to correct problems.

FACILITY: This simulation can be run on any large scientifically oriented digital computer such as the CDC 6600.

SCHEDULE: Simulation should be run later in ACPS development programs, on receipt of design data from component vendors, to perform subsystem simulation prior to design freeze.



SRD 5.1.2.2.3

OMS ENGINE/PROPELLANT DELIVERY SYSTEM SIMULATION

OBJECTIVE: The purpose of this task is to determine the compatibility of the Orbital Maneuvering System (OMS) engine with the propellant delivery system through computer simulation of the system's components. The simulation will also determine the adequacy of the design from a component stress standpoint.

JUSTIFICATION: Pressure variation due to water hammer shocks and fluid flow instabilities in certain components can overstress the system. Engine performance can be degraded by excessive pressure losses or gas bubbles in the feedline. These effects are readily implemented and investigated in a computer simulation of the system.

DESCRIPTION: This simulation will consist of math models of the OMS system including engine, feedlines, tankage valves, flex lines, and bellows mathematically interconnected to form a model of the OMS system. The feed system component models will reflect the component's effect on pressure and flow in the liquid system, and temperature at the engine inlet. The engine components will be integrated by the engine manufacturer into a model providing the thrust response to inlet pressure and temperature and the loading effects on the feed system.

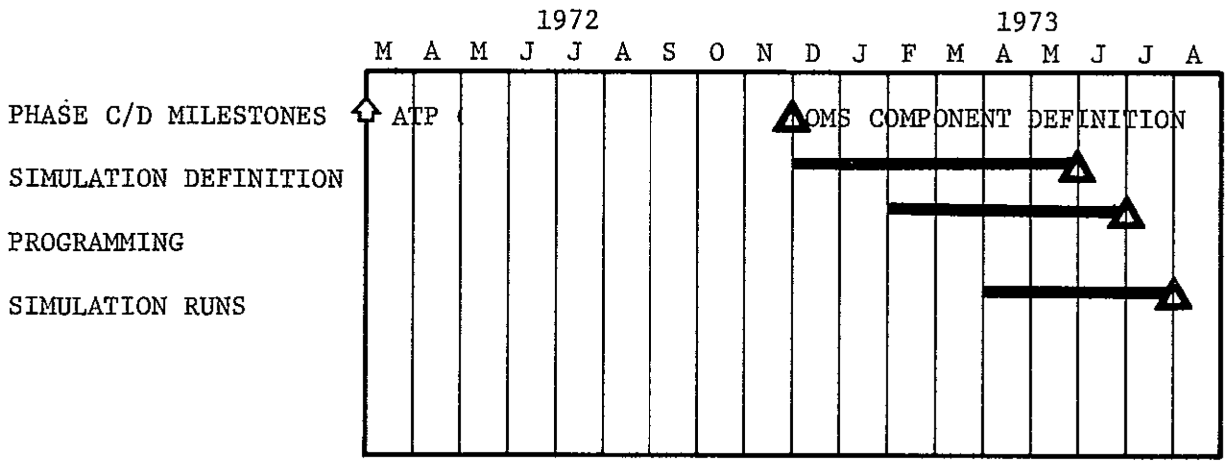
With this model the performance and stability of the OMS can be evaluated. The model will be subjected to normal orbital maneuvering thrust commands while pressure and flowrates throughout the system are computed. Excessive stresses due to "water hammer" vibrations or fluid flow instabilities will reveal themselves if present,suggesting component design changes to suppress such vibrations. Fuel consumption and engine performance (specific impulse) will also be computed. Fuel pressure increases due to vehicle acceleration will be included in the model but rigid body vehicle dynamics will be assumed. The POGO phenomenon will not be present during an OMS burn due to the low power levels associated with the OMS engines and the short feedlines connecting the propellant tanks to the engines.

With the model, parameters will be varied to determine the sensitivities of system performance to component behavior variations.

This simulation will be performed digitally using a scientific programming language such as Fortran.

FACILITY: This work can be performed on any general purpose digital computer with standard peripherals.

SCHEDULE: Simulation should be run when vendor component data is available in order to verify and aid in system design.



SRD 5.1.2.2.4

ACPS/OMS START TANK BREADBOARD

OBJECTIVE: This simulation will assess the effectiveness of the screen retention device for zero "g" propellant positioning. This device must position the cryogenic liquid at the tank drain port in spite of a number of thermal and vibrational disturbances.

JUSTIFICATION: Techniques of zero "g" handling of cryogenic propellants are not well developed at this time. Therefore, considerable analysis and testing is required to ensure adequate performance. The heat transfer effects within the tank defy modeling or prediction to an extent that would provide confidence in the design. Only a breadboard of the tankage system will provide the required high-confidence data on this critical system.

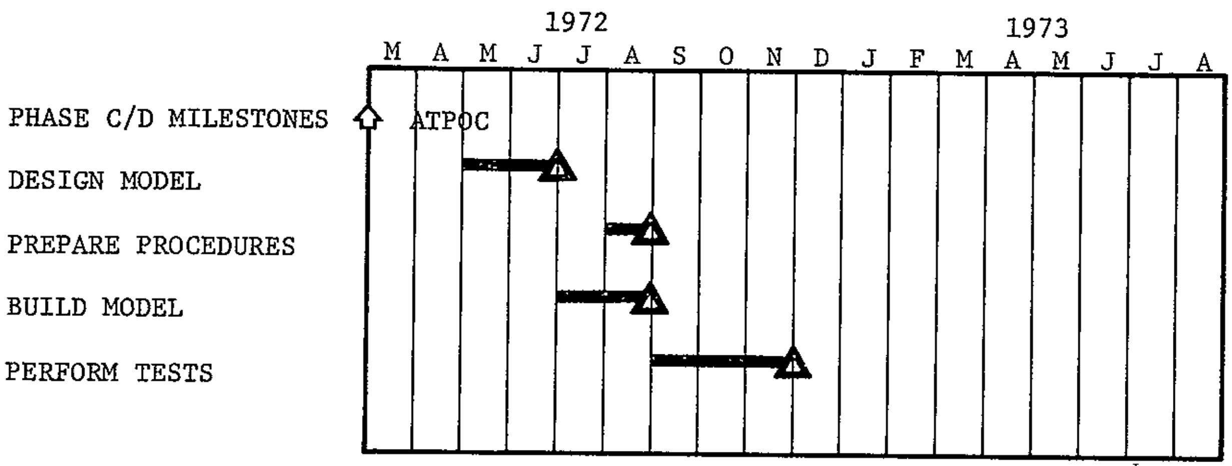
DESCRIPTION: The start tanks are cryogenic fluid containers, within the main propellant tanks that are lined with a fine mesh screen. The diameter of the holes in this screen is on the order of microns. The effect of the screen is to trap liquid between it and the tank wall by surface tension forces, and thereby to present liquid at the drain port at all times. As long as the entire screen is wetted by liquid on its back side, small forces will prefer to move liquid across a liquid/liquid interface, where such interface exists, rather than to break the gas/liquid interface where it exists. Sufficiently large forces will cause the gas bubble to break through. Also heating of the screen can generate bubbles behind the screen and perhaps break the surface tension.

This simulation will construct a subscale model of the tankage system suitable for operation in one "g". The screen grid will not be reduced dimensionally, but the tank size will be reduced to the extent that the liquid head will produce forces expected under zero "g". The entire tank will be immersed in liquid propellant (LOX or LH_2) as it is in the real system. The tank will be required to operate properly upside down (negative one "g"), thereby ensuring that it will operate in zero "g".

In addition to the negative one "g" environment, the tank will be subjected to expected shock and vibration levels and thermal inputs from the helium start tank pressurant and the main tank gas bubble. The results will indicate whether or not additional thermal insulation or mechanical isolation is required in the design to prevent breaking of the surface tension by vibration or boiloff.

FACILITY: This simulation will require a cryogenic laboratory equipped with liquid hydrogen and liquid oxygen, and the associated storage and handling equipment. In addition, a supply of low temperature helium is required as the start tank pressurant.

SCHEDULE: Simulation is run early to aid in early definition of hardware specifications.



SRD 5.1.3.1.1

BOOSTER PROPULSION JET FLAP/AIRBREATHER

OBJECTIVE: The purpose of this task is to establish necessary inlet/exit jet flap geometry and provide a tool to analyze aerodynamic behavior resulting from jet flap operation. Effective use of this tool should result in maximizing range capability. Outputs should include:

- optimum jet deflection angle
- optimum thrust level
- optimum altitude
- minimum control speed
- pressure and force data
- boundary layer and flow visualization information

JUSTIFICATION: Each combination of jet deflection angle and thrust level results in a unique set of trimmed conditions. It is not possible to derive this information from established curves. The most efficient way to establish maximum range for various combinations of parameters is thru the use of a computer program.

DESCRIPTION: This will be a digital simulation for which math models are established to combine the various parametric functions as stated herein. This program will provide a tool for analyzing the jet flap operation for various geometric configurations which limit the ability of the flap to turn the jet and the ability of the jet to negotiate severe pressure gradients. Input parameters that will be varied are:

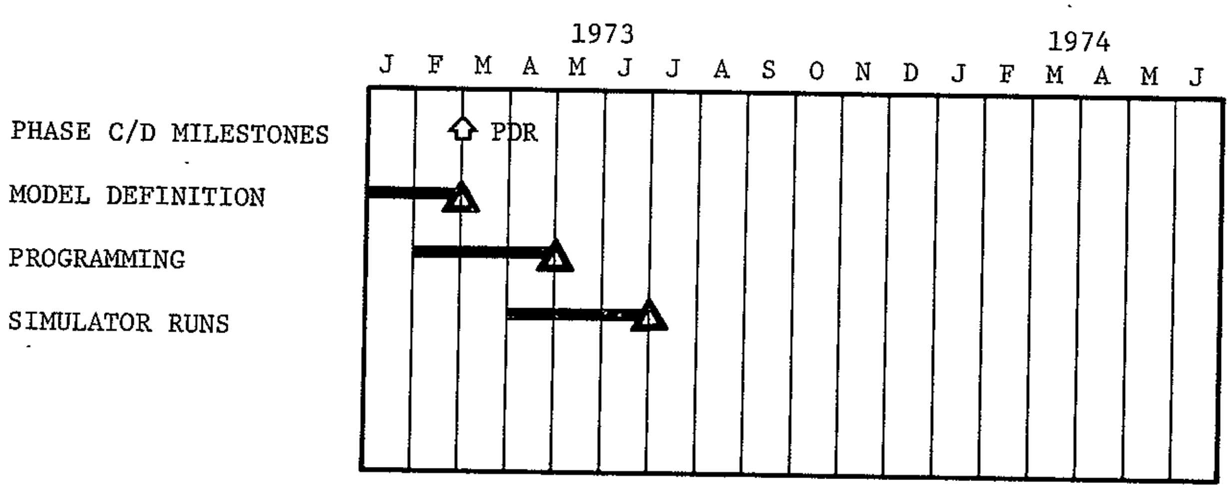
- thickness of jet
- flap geometry
- jet pressure ratio
- jet flow
- weight
- angle of attack
- speed
- altitude
- jet deflection angle
- thrust level
- drag coefficient

The program should be exercised for various operating conditions which include:

- o the effects of jet/flap canard/body interferences
- o ground proximity
- o all engines operating at maximum thrust
- o one engine inoperative
- o winds at various altitudes
- o side slip
- o bank angles
- o several engines out (various combinations)

FACILITY: A scientifically oriented digital computer should be used to run this simulation.

SCHEDULE: Simulation is performed when ferry trajectory data and ABES data are available.



SRD 5.2.1.1.1

BOOSTER DATA MANAGEMENT SYSTEM BREADBOARD

OBJECTIVE: The purpose of the Data Management System (DMS) breadboard is to provide a means of demonstrating the feasibility of the DMS design concept. Specifically, this simulation will investigate:

- o synchronization of two computers
- o voting of computer inputs from redundant sensors
- o voting of computer outputs by a System Control Unit (SCU)
- o failure detection and isolation
- o system reconfiguration

JUSTIFICATION: The complexity and criticality of the DMS dictates that a thorough testing of the design concept be performed. The breadboard approach to the problem will provide confidence that the system concepts work in an actual hardware implementation.

DESCRIPTION: The data management system breadboard will be made up of various pieces of prototype and/or substitute hardware representative of the proposed DMS design. An SCU will control two computers, each of which is equipped with an Input/Output Control Unit (IOCU). Each IOCU will be connected to each of four data busses which carry data to and from a number of Digital Interface Units (DIU) (see figure).

The SCU will be specially built for this application. Its functions will be the same as those of the flight article, but internal redundancy will not be included since this merely serves to make the SCU functions insensitive to SCU failures. This feature is not required to evaluate the system concept.

The computers will be similar to the flight computer in logic design and organization but may be off-the-shelf items if a suitable mini-computer can be found. The essential similarities lie in the areas of:

- o instruction repertoire
- o memory access scheme
- o memory cycle steal.

The IOCU's can be incorporated in the computers if no off-the-shelf computer is suitable. Otherwise the IOCU's will be separate, specially built units. The four data busses and eight or so DIU's will be specially built for this purpose.

The software required for the substitute or breadboard computers includes:

- basic executive structure
- data bus software
- sensor voting
- reconfiguration routines

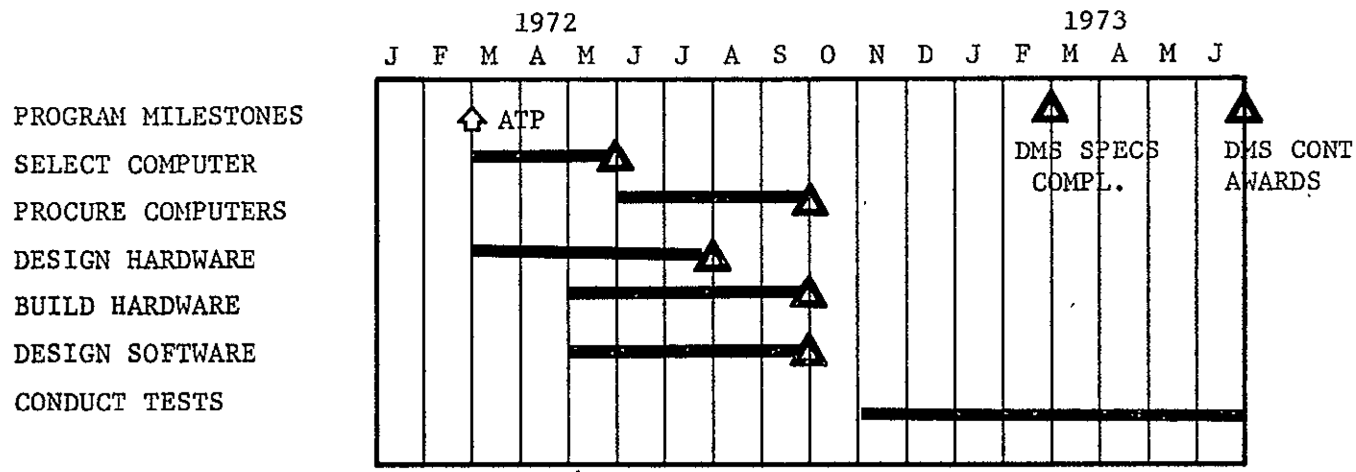
Interfacing with this system will be an input/output device such as a teletypewriter or electric typewriter to communicate with the computers, a control panel functionally equivalent to the cockpit control panel, simulated and actual Line Replaceable Units (LRU) connected to the DIU's, and special logic and switching hardware to simulate failure combinations and sequences. In addition, power supplies and interconnecting cabling will be required.

It is desirable that several functions of the DMS be examined carefully. One such function is the synchronization of the two computers. The stability of the synchronized operation of the two computers over a long period of time will be evaluated.

Another function is the voting of computer inputs by the computer and of computer outputs by the SCU. By simulating various combinations of subsystem failures and observing subsequent system performance, the ability of the system to perform fault detection and isolation, and to then reconfigure the system appropriately will be evaluated.

FACILITY: This breadboard work will be performed in an electronic systems laboratory containing power supplies and standard electronic test equipment. The breadboard shall evolve into a full-scale Avionics Systems Test Unit (ASTU) as additional prototype and actual flight hardware becomes available. This laboratory is the nucleus of the systems integration laboratory described in Appendix E.

SCHEDULE: The simulated Data Management System shall be used intermittently as a breadboard device for support of system development prior to completion of full scale ASTU.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PROGRAM MILESTONES
SELECT COMPUTER
PROCURE COMPUTERS
DESIGN HARDWARE
BUILD HARDWARE
DESIGN SOFTWARE
CONDUCT TESTS
ATP
DMS SPECS COMPL.
DMS CONT AWARDS

SRD 5.2.1.2.1

ORBITER DATA MANAGEMENT SYSTEM BREADBOARD

OBJECTIVE: The purpose of the Data Management System (DMS) breadboard is to provide a means of demonstrating the feasibility of the DMS design concept. Specifically, this simulation will investigate:

- o synchronization of two computers
- o voting of computer inputs from redundant sensors
- o voting of computer outputs by a System Control Unit (SCU)
- o failure detection and isolation
- o system reconfiguration

JUSTIFICATION: The complexity and criticality of the DMS dictates that a thorough testing of the design concept be performed. The breadboard approach to the problem will provide confidence that the system concepts work in an actual hardware implementation.

DESCRIPTION: The data management system breadboard will be made up of various pieces of prototype and/or substitute hardware representative of the proposed DMS design. An SCU will control two computers, each of which is equipped with an Input/Output Control Unit (IOCU). Each IOCU will be connected to each of four data busses which carry data to and from a number of Digital Interface Units (DIU) (see figure).

The SCU will be specially built for this application. Its functions will be the same as those of the flight article, but internal redundancy will not be included since this merely serves to make the SCU functions insensitive to SCU failures. This feature is not required to evaluate the system concept.

The computers will be similar to the flight computer in logic design and organization but may be off-the-shelf items if a suitable mini-computer can be found. The essential similarities lie in the areas of:

- o instruction repertoire
- o memory access scheme
- o memory cycle steal.

The IOCU's can be incorporated in the computers if no off-the-shelf computer is suitable. Otherwise the IOCU's will be separate, specially built units. The four data busses and eight or so DIU's will be specially built for this purpose.

The software required for the substitute or breadboard computers includes:

- o basic executive structure
- o data bus software
- o sensor voting
- o reconfiguration routines

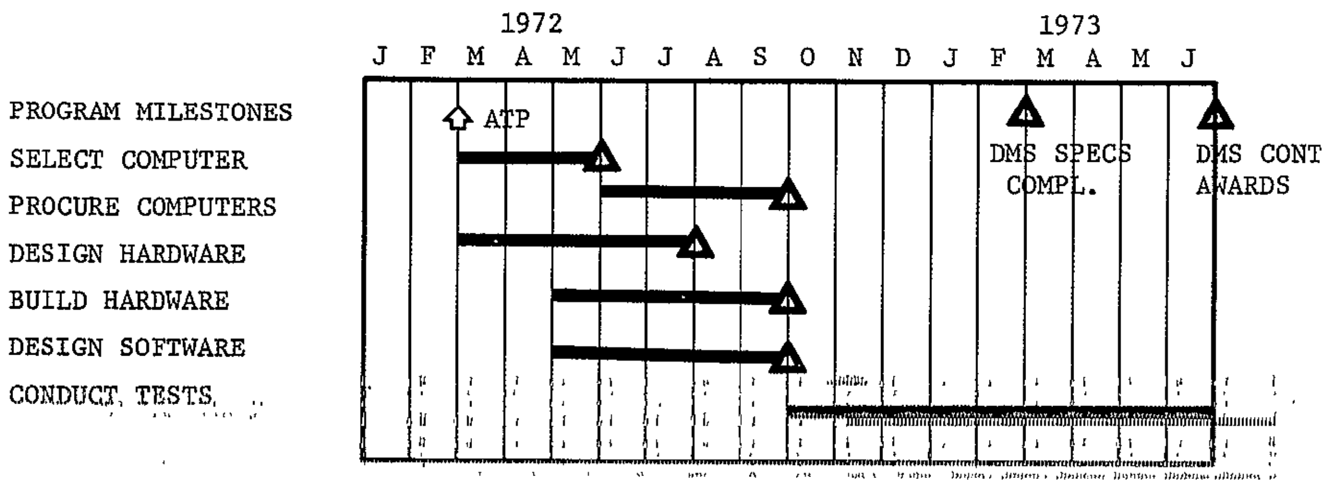
Interfacing with this system will be an input/output device such as a teletypewriter or electric typewriter to communicate with the computers, a control panel functionally equivalent to the cockpit control panel, simulated and actual Line Replaceable Units (LRU) connected to the DIU's, and special logic and switching hardware to simulate failure combinations and sequences. In addition, power supplies and interconnecting cabling will be required.

It is desirable that several features of the DMS be examined carefully in this test. One such feature is the synchronization of the two computers. This test will determine how stably the synchronized operation of the two computers will remain over a long period of time.

Another feature is the voting of computer inputs by the computer and of computer outputs by the SCU. By simulating various combinations of subsystem failures and observing subsequent system performance, this test will determine the ability of the system to perform fault detection and isolation, and to then reconfigure the system appropriately.

FACILITY: This breadboard work will be performed in an electronic systems laboratory containing power supplies and standard electronic test equipment. The breadboard shall evolve into a full-scale Avionics Systems Test Unit (ASTU) as additional prototype and actual flight hardware becomes available. This laboratory is the nucleus of the systems integration laboratory described in Appendix E.

SCHEDULE: The simulated Data Management System shall be used intermittently as a breadboard device for support of system development prior to completion of full scale ASTU.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PROGRAM MILESTONES
SELECT COMPUTER
PROCURE COMPUTERS
DESIGN HARDWARE
BUILD HARDWARE
DESIGN SOFTWARE
CONDUCT TESTS
ATP
DMS SPECS
COMPL.
DMS CONT
AWARDS

SRD 5.2.2.1.1

BOOSTER THRUST VECTOR CONTROL SYSTEM SIMULATION

OBJECTIVE: The objectives of this simulation are to determine the requirements for gimbal actuators during various flight phases and conditions and establish initial design values for autopilot gains and feedback schemes. Outputs should include:

- o Determination of maximum equivalent thrust vector angle (pitch and yaw)
- o Determination of maximum equivalent slew rate (deg/sec)
- o Average deflection angle of duty cycle
- o Ratio of thrust impulse to total vehicle vacuum thrust impulse

JUSTIFICATION: Actuator requirements are necessary for use in developing other associated system designs such as hydraulic, autopilot, guidance and navigation. These actuator design parameters could be determined on a fabricate and test basis, but this could not be done in a timely or economical manner.

DESCRIPTION: This should be a three degree of freedom computer simulation utilizing math models of the combined vehicle dynamic characteristics and the autopilot gain control system. Computer inputs should control the various parameters necessary to exercise the system through the various phases and conditions of operation to determine gimbal actuator limitations.

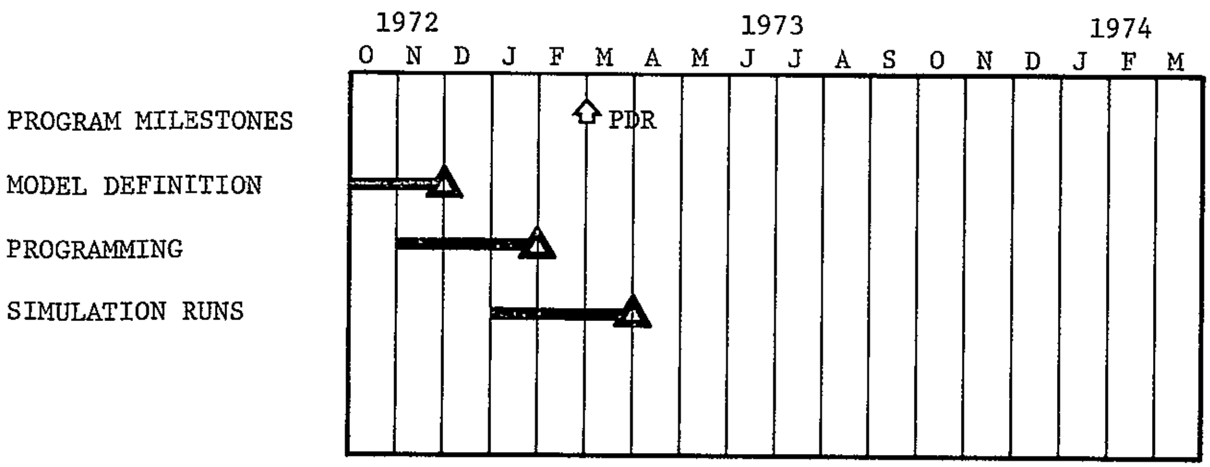
Ascent trajectory model data should be used as inputs to this simulation. Other inputs that should be included are:

- o Assumed launch site wind profile
- o Aerodynamic characteristics as function of mach number
- o Initial autopilot gains
- o Tilt program
- o Vehicle cg location as function of time
- o Pitch moment of inertia as function of time

The effects of cg offset and engine out on autopilot parameters and equivalent thrust vector angle and slew rate could also be investigated with this simulation.

FACILITY: A general purpose digital computer with standard peripherals is required for this simulation.

SCHEDULE: This program should be run after the ascent trajectory analysis is complete and input data is available.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PDR
MODEL DEFINITION
PROGRAMMING
SIMULATION RUNS

SRD 5.2.2.1.2

BOOSTER FLIGHT CONTROL SYSTEM/HYDRAULIC SYSTEM INTERFACE VERIFICATION

OBJECTIVE: The objective of this task is to verify the Flight Control System (FSC) and hydraulic actuator-control surface hardware interface in lateral and longitudinal control modes of aerodynamic flight. Outputs from this simulation shall include:

- o Verification of flight control system stability augmentation software interface with vehicle control system hardware.
- o Effects of hardware nonlinearities and system stability.
- o Correlation with digital simulation data for all conditions of aerodynamic flight - lateral and longitudinal modes (SRD 4.1.1.1)
- o Correlation with man-in-the-loop handling characteristics digital simulation (SRD 1.1.1.1.2)
- o Evaluation of man-in-the-loop handling characteristics at various flight conditions.
- o Evaluation of crew station flight control devices (i.e., control stick, pedals, etc.)

JUSTIFICATION: Flight simulation using actual hardware in the control loop serves as a valuable tool in this verification of design analyses. Nonlinearities normally not considered in system math models in early analyses are now incorporated into system evaluations. If problems exist, they may be solved using flight simulation as an aid in the solution. If no problems exist, added confidence in the system design is acquired. Flight simulation using increasing amounts of actual hardware in the system mechanization is a natural progression in flight control system hardware development.

DESCRIPTION: Flight control electronics, hydraulic actuators, control surfaces and vehicle flight characteristics shall be combined in a flight simulation test utilizing the hydraulics and avionics systems test facilities and GN&C crew station. Operational system loop shall be closed with a simulation computer to provide functional simulation of the orbiter vehicle aerodynamic flight phase.

Simulation software shall include math models of vehicle lateral-directional and longitudinal equations of motion, environment, aerodynamic surface loads, simulated vehicle flight software for control of data management, hydraulics, and flight controls subsystems including stability augmentation for all aerodynamic flight conditions.

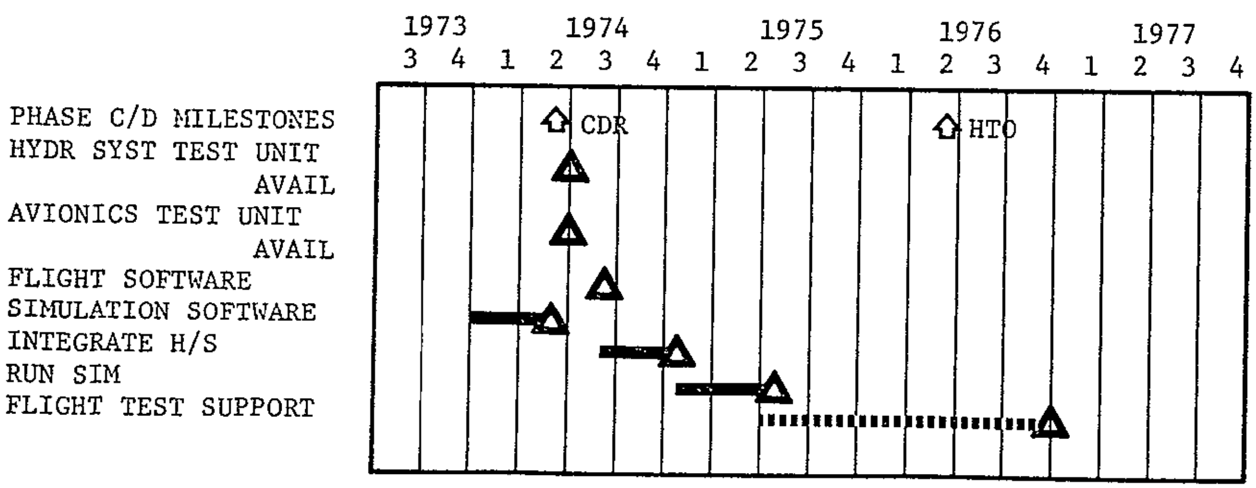
The simulation task shall be performed in two parts. The first part shall consist of unmanned simulation runs to correlate vehicle control system responses with design analyses previously run on all-digital simulations. System transient responses shall be evaluated for all critical flight conditions throughout the aerodynamic flight regime. Part two shall consist of evaluation of vehicle handling characteristics using man-in-the-loop simulation procedures. Vehicle stability augmentation effects on manual control shall be evaluated and correlated to design analyses for critical flight conditions.

FACILITY: The following integrated facilities are required to perform this simulation:

- o Hydraulics and Controls Test Unit including flight control actuators, landing system actuators, and simulated aerodynamic surface inertias and dynamic loads on the flight control actuators.
- o Avionics System Test Unit including flight control system and data management avionics hardware.
- o Vehicle crew station mockup.
- o Simulation computer and hardware interfaces.

Details of the ASTU and HCTU are presented in Appendix E.

SCHEDULE: This task shall be performed before hardware/software verification, but late in the development phase when prototype FCS hardware subsystems are available in order to verify subsystems design and interfaces.



SRD 5.2.2.1.3

BOOSTER THRUST VECTOR CONTROL SYSTEM/HYDRAULIC SYSTEM INTERFACE VERIFICATION

OBJECTIVE: The objective of this task is to verify the Thrust Vector Control (TVC) system and hydraulic actuator interface through flight simulation techniques. The TVC subsystem hardware will be combined with reference environment math models and vehicle equations of motion software simulations to evaluate thrust vector control subsystem operation during orbiter boost phase. Outputs of this simulation study include:

- Verification of Thrust Vector Control subsystem electronics interface with hydraulic actuator and guidance subsystem
- Effects of hardware nonlinearities on system stability and system errors
- Correlation with digital simulation analysis of orbiter boost phase

JUSTIFICATION: Flight simulation using actual hardware in the control loop serves as a valuable tool in the verification of design analyses. Nonlinearities normally not considered in system evaluations by addition of hardware components. If problems are found to exist, they may be solved using flight simulation techniques as an aid in the solution. If no problem exists, added confidence in the system design is acquired through verification by flight simulation.

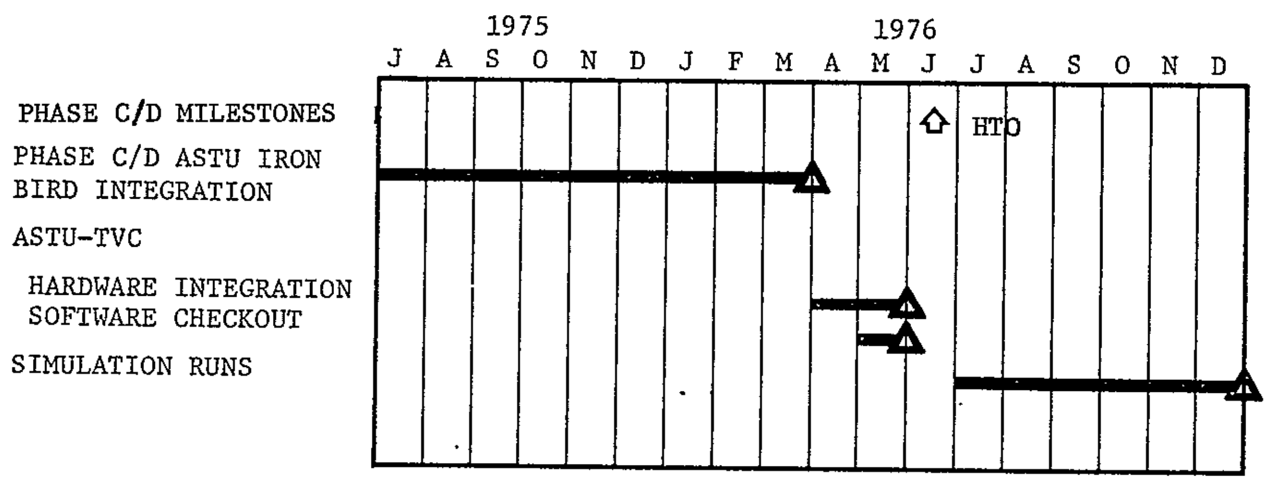
DESCRIPTION: Inputs to this verification simulation include design data on stiffness, mass, and inertia of main engine gimballing system, actual TVC hydraulic actuator/hydraulic supply system, and boost phase GN&C avionics. Hardware portion of this simulation shall include a main engine gimbal test stand, three-axis flight simulator, simulation computer, TVC hydraulic actuator and hydraulic supply, and boost-phase flight control system electronics, guidance system electronics, and data management system. The main engine gimbal test stand shall provide a mechanical simulation of main engine inertia, gimbal friction, spring mass of propellant lines, and stiffness of simulated engine and actuator backup structure. The three-axis flight simulator shall provide angular rates and attitudes for IMU and rate gyro sensors during the boost phase simulation. The real-time computer mechanization of vehicle dynamics interfaced with system hardware shall complete the closed-loop system simulation.

Software modules shall include simulated reference environment (vehicle model, dynamics model, gravitational acceleration model, winds model) and applicable portions of vehicle guidance navigation and control programs.

The simulation task shall be performed to evaluate the TVC system hardware and electronics interface and system dynamics during boost phase. Input disturbances such as turbulence and gusts will serve as forcing functions to evaluate system stability.

FACILITY: Certain portions of the Systems Integration Laboratory previously listed are required for this simulation. The computer is a general purpose digital computer. The Systems Integration Laboratory is described in Appendix E.

SCHEDULE: The verification simulation shall be run when TVC system prototype hardware and boost phase GN&C software is sufficiently developed to validate TVC hardware design and interfaces with hydraulics and avionics subsystems.



SRD 5.2.2.2.1

ORBITER FLIGHT CONTROL SYSTEM/HYDRAULIC SYSTEM INTERFACE VERIFICATION

OBJECTIVE: The objective of this task is to verify the Flight Control System (FSC) and hydraulic actuator-control surface hardware interface in lateral and longitudinal control modes of aerodynamic flight. Outputs from this simulation shall include:

- o Verification of flight control system stability augmentation software interface with vehicle control system hardware.
- o Effects of hardware nonlinearities and system stability.
- o Correlation with digital simulation data for all conditions of aerodynamic flight - lateral and longitudinal modes (SRD 4.1.2.1)
- o Correlation with man-in-the-loop handling characteristics digital simulation (SRD 1.1.1.2.2)
- o Evaluation of man-in-the-loop handling characteristics at various flight conditions.
- o Evaluation of crew station flight control devices (i.e., control stick, pedals, etc.)

JUSTIFICATION: Flight simulation using actual hardware in the control loop serves as a valuable tool in this verification of design analyses. Nonlinearities normally not considered in system math models in early analyses are now incorporated into system evaluations. If problems exist, they may be solved using flight simulation as an aid in the solution. If no problems exist, added confidence in the system design is acquired. Flight simulation using increasing amounts of actual hardware in the system mechanization is a natural progression in flight control system hardware development.

DESCRIPTION: Flight control electronics, hydraulic actuators, control surfaces and vehicle flight characteristics shall be combined in a flight simulation test utilizing the hydraulics and avionics systems test facilities and GN&C crew station. Operational system loop shall be closed with a simulation computer to provide functional simulation of the orbiter vehicle aerodynamic flight phase.

Simulation software shall include math models of vehicle lateral-directional and longitudinal equations of motion, environment, aerodynamic surface loads, simulated vehicle flight software for control of data management, hydraulics, and flight controls subsystems including stability augmentation for all aerodynamic flight conditions.

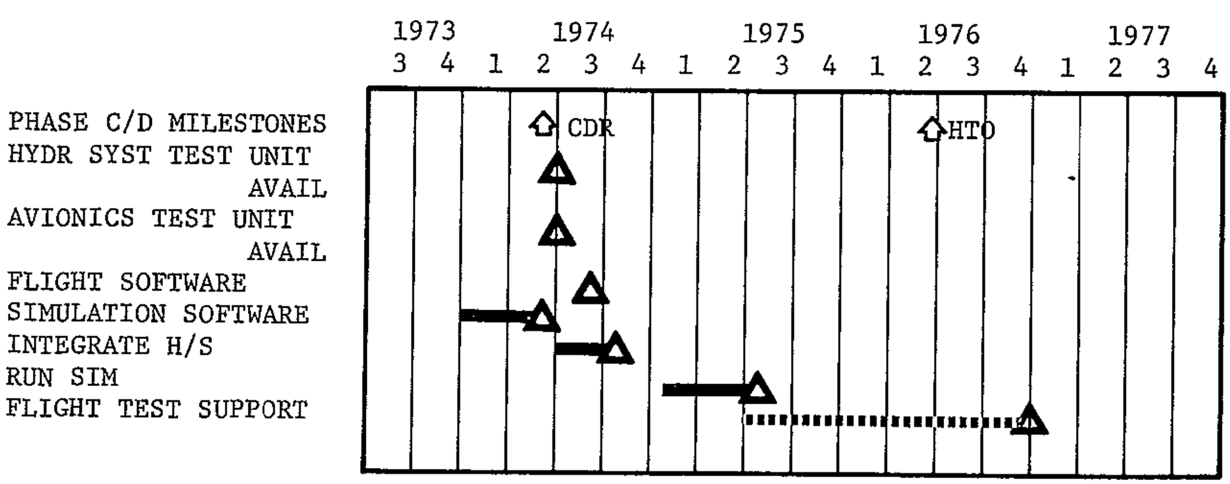
The simulation task shall be performed in two parts. The first part shall consist of unmanned simulation runs to correlate vehicle control system responses with design analyses previously run on all-digital simulations. System transient responses shall be evaluated for all critical flight conditions throughout the aerodynamic flight regime. Part two shall consist of evaluation of vehicle handling characteristics using man-in-the-loop simulation procedures. Vehicle stability augmentation effects on manual control shall be evaluated and correlated to design analyses for critical flight conditions.

FACILITY: The following integrated facilities are required to perform this simulation:

- o Hydraulics and Controls Test Unit including flight control actuators, landing system actuators, and simulated aerodynamic surface inertias and dynamic loads on the flight control actuators.
- o Avionics System Test Unit including flight control system and data management avionics hardware.
- o Vehicle crew station mockup.
- o Simulation computer and hardware interfaces.

Details of the ASTU and HCTU are presented in Appendix E.

SCHEDULE: This task shall be performed before hardware/software verification, but late in the development phase when prototype FCS hardware subsystems are available in order to verify subsystems design and interfaces.



SRD 5.2.2.2.2

ORBITER THRUST VECTOR CONTROL SYSTEM/HYDRAULIC SYSTEM INTERFACE VERIFICATION

OBJECTIVE: The objective of this task is to verify the Thrust Vector Control (TVC) system and hydraulic actuator interface through flight simulation techniques. The TVC subsystem hardware will be combined with reference environment math models and vehicle equations of motion software simulations to evaluate thrust vector control subsystem operation during orbiter boost phase. Outputs of this simulation study include:

- o Verification of Thrust Vector Control subsystem electronics interface with hydraulic actuator and guidance subsystem
- o Effects of hardware nonlinearities on system stability and system errors
- o Correlation with digital simulation analysis of orbiter boost phase

JUSTIFICATION: Flight simulation using actual hardware in the control loop serves as a valuable tool in the verification of design analyses. Nonlinearities normally not considered in system evaluations by addition of hardware components. If problems are found to exist, they may be solved using flight simulation techniques as an aid in the solution. If no problem exists, added confidence in the system design is acquired through verification by flight simulation.

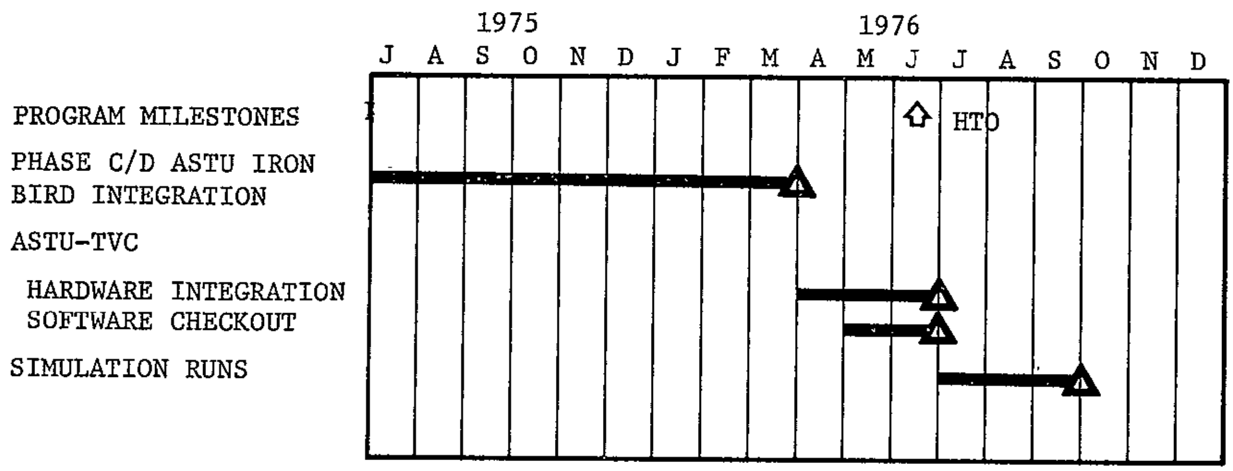
DESCRIPTION: Inputs to this verification simulation include design data on stiffness, mass, and inertia of main engine gimballing system, actual TVC hydraulic actuator/hydraulic supply system, and boost phase GN&C avionics. Hardware portion of this simulation shall include a main engine gimbal test stand, three-axis flight simulator, simulation computer, TVC hydraulic actuator and hydraulic supply, and boost-phase flight control system electronics, guidance system electronics, and data management system. The main engine gimbal test stand shall provide a mechanical simulation of main engine inertia, gimbal friction, spring mass of propellant lines, and stiffness of simulated engine and actuator backup structure. The three-axis flight simulator shall provide angular rates and attitudes for IMU and rate gyro sensors during the boost phase simulation. The real-time computer mechanization of vehicle dynamics interfaced with system hardware shall complete the closed-loop system simulation.

Software modules shall include simulated reference environment (vehicle model, dynamics model, gravitational acceleration model, winds model) and applicable portions of vehicle guidance,navigation and control programs.

The simulation task shall be performed to evaluate the TVC system hardware and electronics interface and system dynamics during boost phase. Input disturbances such as turbulence and gusts will serve as forcing functions to evaluate system stability.

FACILITY: Certain portions of the Systems Integration Laboratory previously listed are required for this simulation. The computer is a general purpose digital computer. The Systems Integration Laboratory is described in Appendix E.

SCHEDULE: The verification simulation shall be run when TVC system prototype hardware and boost phase GN&C software is sufficiently developed to validate TVC hardware design and interfaces with hydraulics and avionics subsystems.



SRD 5.2.3.1.1

BOOSTER AVIONICS SIMULATION - AUTOPILOT FUNCTIONAL VERIFICATION

OBJECTIVE: The objective of this simulation is to verify the interface between orbiter flight control subsystem, navigation and guidance subsystem, and hydraulics subsystem, and the function of the autopilot mode of flight control. Specific outputs of this simulation shall be verification of integrated systems operation and hardware/software interface of the following automatic flight control modes:

- o Automatic angle of attack
- o Heading hold
- o Altitude hold
- o Automatic velocity control

Additional investigations shall include:

- o Subsystem response to transition from manual to automatic mode
- o Correlation with digital simulation data for automatic control
- o Subsystem hardware/software interface verification
- o Verification of G&N and flight control subsystems hardware interface

JUSTIFICATION: Flight simulation has proven to be an extremely useful technique for verification of avionics hardware and hardware/software interfaces. Introduction of simulated flight conditions into the flight control avionics hardware loop provides the most rigid ground test possible for determination of hardware capability in actual operating conditions.

DESCRIPTION: Major components of the simulation include a single nonredundant avionics system consisting of data management subsystem, flight control subsystem, and certain portions of the guidance and navigation subsystem, hydraulics and aerodynamics surface controls, simulation computer/interface, and crew station. Flight control subsystem will consist of hardware configuration used in earlier flight control system simulations (SRD 5.2.2.1.2). Guidance and navigation subsystem shall include velocity and position sensing hardware. Accelerometer and air data sensors shall be simulated by extracting required terms from appropriate vehicle reference environment and equations of motion data.

Data management subsystem including vehicle flight computer shall consist of actual data bus hardware required to interface all avionics/hydraulics hardware. Vehicle flight software shall consist of vehicle avionics and hydraulics subsystem management programs and GN&C modules for aerodynamic flight phase.

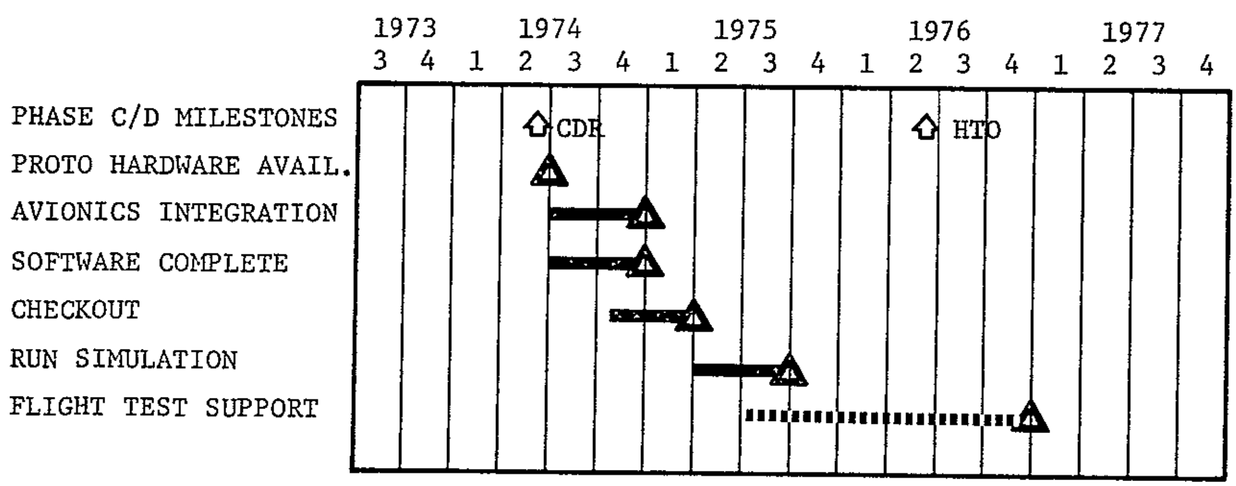
Hydraulics and aerodynamics surface control system used in this simulation shall be configured as described in SRD 5.4.2.1.2. The crew station cockpit shall include all avionics displays and controls related to the autopilot flight mode for monitoring system operation and controlling operating modes.

Simulation computer shall provide mechanization of vehicle equations of motion for lateral and longitudinal modes of flight, reference environment, guidance and navigation sensors, and inputs to appropriate crew station displays and controls.

Runs will consist of operating the closed-loop vehicle real-time hardware-software simulation in either lateral or longitudinal mode to evaluate autopilot stability and control characteristics in the presence of disturbances such as winds and wind gusts.

FACILITY: The facility required is the Systems Integration Laboratory (described in Appendix E) consisting of avionics system test unit, hydraulic and controls test unit, crew station, and simulation computer.

SCHEDULE: This simulation shall follow flight control subsystem/hydraulic subsystem interface verification (SRD 5.2.2.1.2) and shall be completed before full scale hardware/software verification tests.



SRD 5.2.3.2.1

ORBITER AVIONICS SIMULATION - AUTOMATIC LANDING FUNCTIONAL VERIFICATION

OBJECTIVE: The objective of this simulation is to evaluate orbiter GN&C avionics, communications/navaids avionics, and hydraulics subsystem interfaces in performance of automatic landing system. Specific outputs will be evaluation of system operation by considering:

- o glide slope hold capability
- o glide slope calculations based on energy management requirements
- o system stability and accuracy
- o hardware/software verification

JUSTIFICATION: Verification of integrated systems design by flight simulation has proven to be an extremely useful technique in flight control systems development. Introduction of simulated flight conditions into the hardware loop provides the best method of verifying hardware interfaces and performance under actual conditions. By adding more hardware, the total system simulation continues to approach actual operating conditions enabling final adjustments of system design and added confidence in the system.

DESCRIPTION: Major components of this simulation include single non-redundant avionics system consisting of data management subsystems, flight controls subsystem, and applicable portions of guidance and navigation and communications/navaids subsystems, hydraulics and aerodynamic surface controls, crew station, and simulation computer/interface.

Flight controls subsystem hardware will be configured as in previous flight control simulations (SRD 5.2.2.2.1 and 5.2.3.2.2). The guidance and navigation subsystem electronics shall include velocity and position sensing hardware mounted on a three-axis table. All navaids hardware, accelerometer and air data sensors shall be simulated by extracting required terms from appropriate vehicle environment math models and equations of motion.

Data management subsystem including vehicle onboard computer shall consist of actual data bus hardware required to interface all avionics/hydraulics hardware. Flight software shall consist of system executive, data bus control, sensor signal processing, display and controls management, guidance and navigation, and mission landing phase modules. The software modules shall be actual flight software developed for orbiter aerodynamic flight.

Navaids inputs to subsystem LRU's shall be mechanized by the simulation computer. Data bus information representing VOR, DME, ILS, and radar altimeter outputs is used by the onboard computer to derive area navigation position and automatic landing guidance commands.

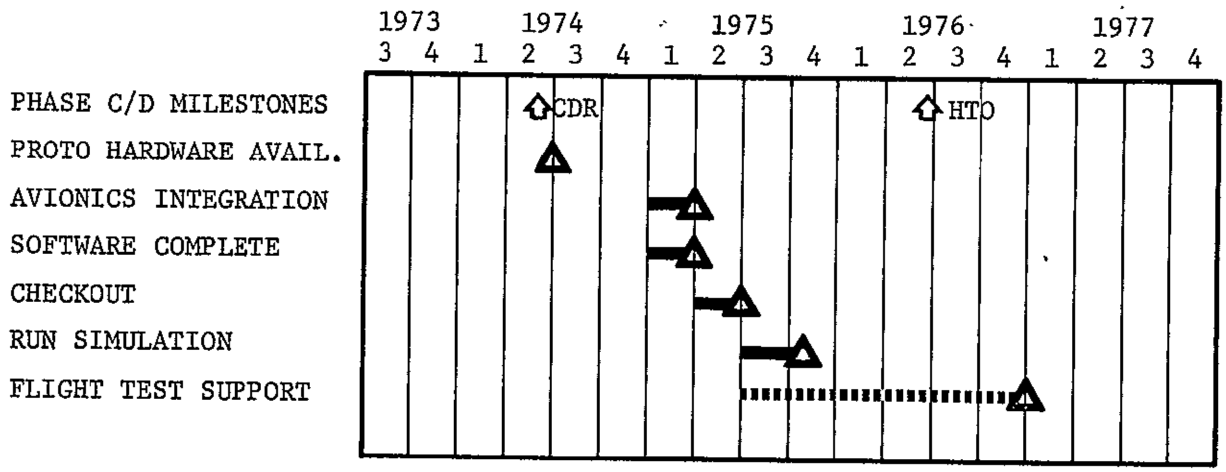
Hydraulics and aerodynamic surface controls used in this simulation shall be configured as described in SRD 5.4.2.2.2 representing actual vehicle hardware in the aerodynamic flight control loop. The crew station shall contain all operational avionics displays and controls related to automatic approach and landing phase for the purpose of monitoring system status and controlling operating modes.

The simulation computer shall provide mechanization of vehicle equations of motion for a six-degree-of-freedom rigid body as described in SRD 1.1.1.2.2. Reference environment simulation associated with aerodynamic flight in approach and landing phase shall be required. A simplified math model of air breathing propulsion system and its thrust controls shall be mechanized to provide thrust/velocity control data for the system simulation. Other math models included are certain G&N sensors which cannot be operated as actual hardware.

Runs will consist of operating the closed-loop real-time hardware-software simulation of the vehicle automatic landing sequence to evaluate automatic mode stability and control characteristics, as well as manual handling characteristics.

FACILITY: The facility required is a System Integration Laboratory type installation consisting of an Avionics System Test Unit, Hydraulics and Control Systems Test Unit, crew station, and simulation computer. The Systems Integration Laboratory is described in Appendix E.

SCHEDULE: This simulation shall follow SRD's 5.2.2.2.2 and 5.2.3.2.2 in a normal progression of flight control system hardware design and interface verification simulations. This task will be completed prior to full scale software/hardware verification tests.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SOFTWARE COMPLETE
CHECKOUT
RUN SIMULATION
FLIGHT TEST SUPPORT

SRD 5.2.3.2.2

ORBITER AVIONICS SIMULATION - AUTOPILOT FUNCTIONAL VERIFICATION

OBJECTIVE: The objective of this simulation is to verify the interface between orbiter flight control subsystem, navigation and guidance subsystem, and hydraulics subsystem, and the function of the autopilot mode of flight control. Specific outputs of this simulation shall be verification of integrated systems operation and hardware/software interface of the following automatic flight control modes:

- o Automatic angle of attack
- o Heading hold
- o Altitude hold
- o Automatic velocity control

Additional investigations shall include:

- o Subsystem response to transition from manual to automatic mode
- o Correlation with digital simulation data for automatic control
- o Subsystem hardware/software interface verification
- o Verification of G&N and flight control subsystems hardware interface

JUSTIFICATION: Flight simulation has proven to be an extremely useful technique for verification of avionics hardware and hardware/software interfaces. Introduction of simulated flight conditions into the flight control avionics hardware loop provides the most rigid ground test possible for determination of hardware capability in actual operating conditions.

DESCRIPTION: Major components of the simulation include a single nonredundant avionics system consisting of data management subsystem, flight control subsystem, and certain portions of the guidance and navigation subsystem, hydraulics and aerodynamics surface controls, simulation computer/interface, and crew station. Flight control subsystem will consist of hardware configuration used in earlier flight control system simulations (SRD 5.2.2.2.1). Guidance and navigation subsystem shall include velocity and position sensing hardware. Accelerometer and air data sensors shall be simulated by extracting required terms from appropriate vehicle reference environment and equations of motion data.

Data management subsystem including vehicle flight computer shall consist of actual data bus hardware required to interface all avionics/hydraulics hardware. Vehicle flight software shall consist of vehicle avionics and hydraulics subsystem management programs and GN&C modules for aerodynamic flight phase.

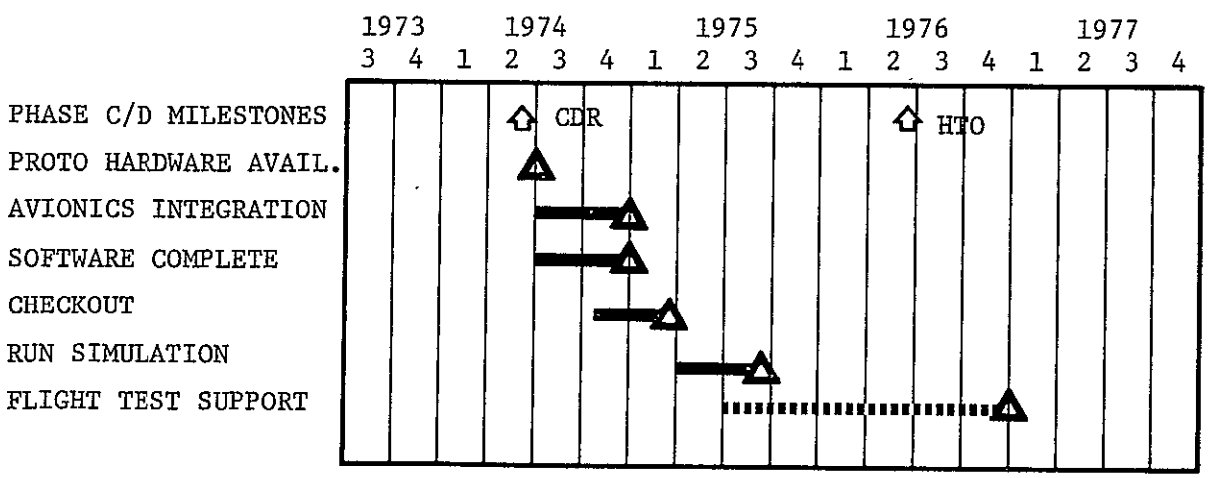
Hydraulics and aerodynamics surface control system used in this simulation shall be configured as described in SRD 5.4.2.2.2. The crew station cockpit shall include all avionics displays and controls related to the autopilot flight mode for monitoring system operation and controlling operating modes.

Simulation computer shall provide mechanization of vehicle equations of motion for lateral and longitudinal modes of flight, reference environment, guidance and navigation sensors, and inputs to appropriate crew station displays and controls.

Runs will consist of operating the closed-loop vehicle real-time hardware-software simulation in either lateral or longitudinal mode to evaluate autopilot stability and control characteristics in the presence of disturbances such as winds and wind gusts.

FACILITY: The facility required is the Systems Integration Laboratory (described in Appendix E) consisting of Avionics System Test Unit, Hydraulic and Controls Test Unit, crew station, and simulation computer.

SCHEDULE: This simulation shall follow flight control subsystem/hydraulic subsystem interface verification (SRD 5.2.2.2.1) and shall be completed before full scale hardware/software verification tests.



SRD 5.3.1.1.1

BOOSTER ECLS SYSTEM SIMULATION

OBJECTIVE: The objective of this simulation is to provide a tool for developing and verifying the booster cockpit and avionics thermal and atmosphere design and to optimize heat control. Outputs from this simulation will include:

- o heat flow rates
- o establishment of thermal control design
- o establishment of atmosphere control design
- o optimized heat control

JUSTIFICATION: To establish a method of determining the optimum cockpit and avionics compartments thermal and atmosphere control design it is necessary to determine the heat flow rates of the areas in which the crewmen interface during the various mission phases. This is a determination that must be made during early design phases to ensure adequate space for cooling and environmental control apparatus.

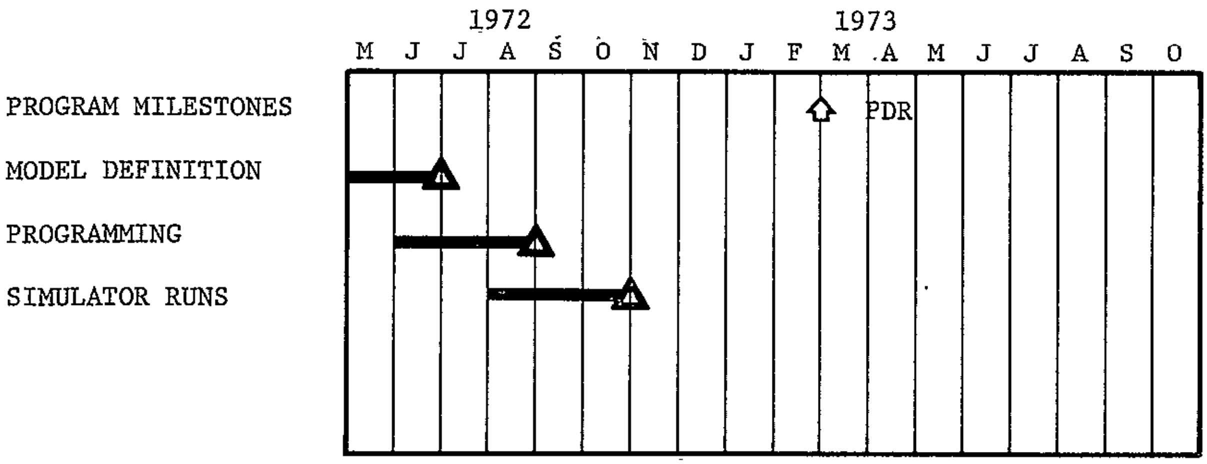
DESCRIPTION: This simulation will require the use of a digital computer model combined with a hardware mockup utilized to optimize heat control. Inputs of the program will include:

- o windshield heat dissipation (transparent area)
- o avionics heat dissipation
- o crewmen metabolic dissipation

These inputs will be derived from other simulations and acquire test data. Existing computer programs can possibly be used with modifications to obtain the desired results. A generalized environmental control and life support system written in Fortran language (e.g., the MDAC developed G-189) can possibly be useful with this simulation.

FACILITY: A scientific digital computer should be utilized in conjunction with a crew compartment hardware mockup to perform this simulation.

SCHEDULE: This simulation should be performed early in phase C and new runs made as significant changes occur.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M J J A S O N D J F M A M J J A S O
PROGRAM MILESTONES
PDR
MODEL DEFINITION
PROGRAMMING
SIMULATOR RUNS

SRD 5.3.1.2.1

ORBITER ENVIRONMENTAL CONTROL/LIFE SUPPORT (ECLS) SYSTEM SIMULATION

OBJECTIVE: This simulation will determine the performance of the ECLS system in the presence of steady state and transient stimuli. It will compute pressure, temperature, flow, gas content, and humidity at various points in the system as a function of time. Outputs from this simulation shall include

- o steady state representation of system operation
- o system time response to transient disturbances.

JUSTIFICATION: Proper operation of the ECLS system during all mission phases is critical to crew safety and comfort. System simulation will provide the confidence required through critical system analysis throughout design and development phase. It will provide a mechanism for subjecting the ECLS system design to worst case demands on the system for testing the limits on performance before hardware is procurred.

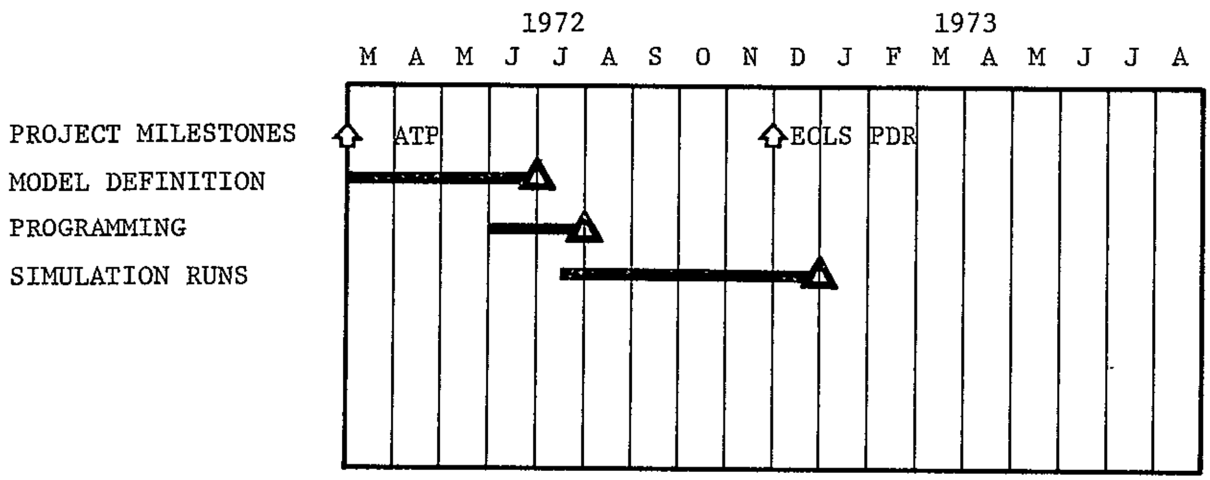
DESCRIPTION: The ECLS system components (pumps, valves, heat exchangers, controls, coldplates, gas storage containers) are modeled to reflect their effects on pressure, temperature, mass flow, heat flow, humidity, or chemical reactions as appropriate. The interactions of the components are represented by modeling equations of mass transfer, heat transfer, chemical reaction, mass and energy balances, and pressure drop-flow balances. Thermal inputs are determined from flight profiles of the vehicle temperature distributions for various mission phases, crew sizes, mission duration, and equipment configurations.

The simulation program shall be made up of a number of subroutines representing individual components with interconnecting computational flow paths combining to simulate the total system. The total system math model will provide time varying solutions describing parameters such as cabin temperature profiles, cabin gas content profiles, and equipment coldplate temperature profiles for various mission phases and system conditions.

A number of generalized programs are available for adopting to orbiter vehicle ECLS system simulation. An example is the G-189 program developed by MDAC for analysis of Apollo command module environmental control system.

FACILITY: This simulation can be on a large scientific digital computer such as the CDC 6600, or equivalent. A common scientific programming language will be used.

SCHEDULE: Simulation shall be modeled and operational early in the program to aid in ECLS system development. Simulation program may be updated and rerun as more current component and thermal environment data is available.



SRD 5.4.1.1.1

BOOSTER D.C. ELECTRICAL DISTRIBUTION SYSTEM ANALYSIS

OBJECTIVE: This program is designed to determine power consumption requirements and thermal heat dissipation for all booster D.C. electrical loads throughout the mission. Outputs from this analysis include:

- o total electrical power dissipated at given equipment locations
- o main power control unit (MPCU) to power distribution unit (PDU) losses
- o timeline presentation of each bus current, voltage
- o timeline presentation of each PDU current, voltage
- o average and total values of load watts for a given time period
- o failure effects on system load distribution

The analysis will be accomplished by a digital computer simulation of electrical system characteristics and booster system power requirements.

JUSTIFICATION: The simulation provides a valuable design aid for maintaining current booster electrical subsystem configuration status throughout the design and development phase. This analysis has proven its utility on past programs. Impact on power distribution and heat dissipation design may be quickly evaluated when contemplating system changes.

DESCRIPTION: A model of the booster electrical system will be written to include:

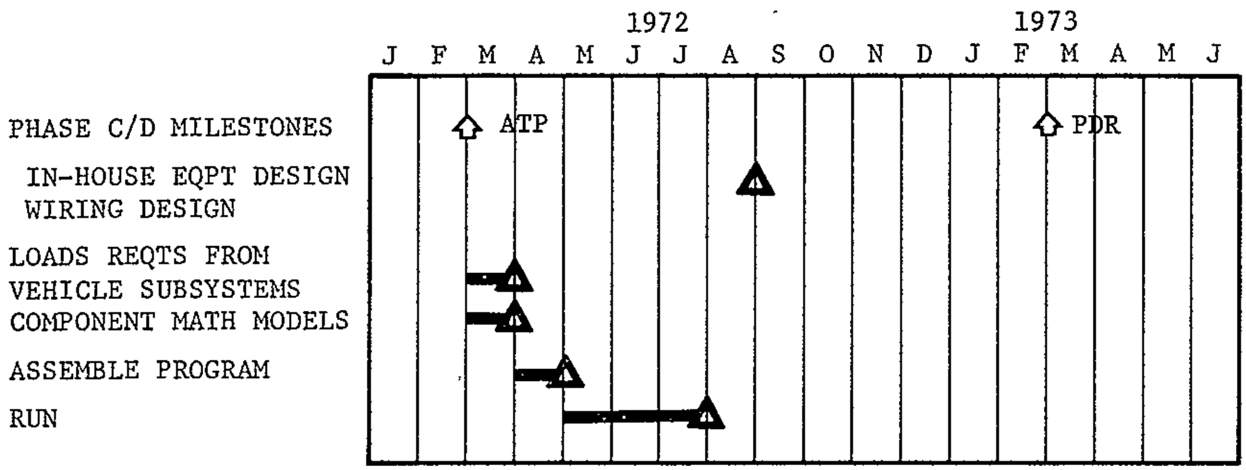
- o point-to-point circuit resistances
- o fuel cell voltage and power characteristics
- o power distribution unit operating characteristics
- o total system switching capabilities
- o thermal characteristics based on power dissipation

Inputs to the math model from other booster subsystems are time histories of power consumption for each LRU within the booster vehicle. These inputs will be provided as available and iterated to reflect improvements in quality of the data. The final data will reflect an extremely accurate representation of the power system.

The simulation shall be programmed in a common scientific language and will be suitable for execution on a large-scale scientific computer. A plotting subroutine will be included to output plots of electrical load timelines for total system, subsystem, power distribution unit, or bus power distribution. No hardware or hardware interface will be required for this computer simulation.

FACILITY: The facility required for this simulation is a scientific computer available at the contractor's facility complex.

SCHEDULE: Program shall be operational early in Phase C and will be used through Phases C/D as needed in vehicle development.



SRD 5.4.1.2.1

ORBITER D.C. ELECTRICAL DISTRIBUTION SYSTEM ANALYSIS

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The analysis will be accomplished by a digital computer simulation of electrical system characteristics and orbiter system power requirements.

JUSTIFICATION: The simulation provides a valuable design aid for maintaining current orbiter electrical subsystem configuration status throughout the design and development phase. This analysis has proven its utility on past programs. Impact on power distribution and heat dissipation design may be quickly evaluated when contemplating system changes.

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- o thermal characteristics based on power dissipation

Inputs to the math model from other orbiter subsystems are time histories of power consumption for each LRU within the orbiter vehicle. These inputs will be provided as available and iterated to reflect improvements in quality of the data. The final data will reflect an extremely accurate representation of the power system.

The simulation shall be programmed in a common scientific language and will be suitable for execution on a large-scale scientific computer. A plotting subroutine will be included to output plots of electrical load timelines for total system, subsystem, power distribution unit, or bus power distribution. No hardware or hardware interface will be required for this computer simulation.

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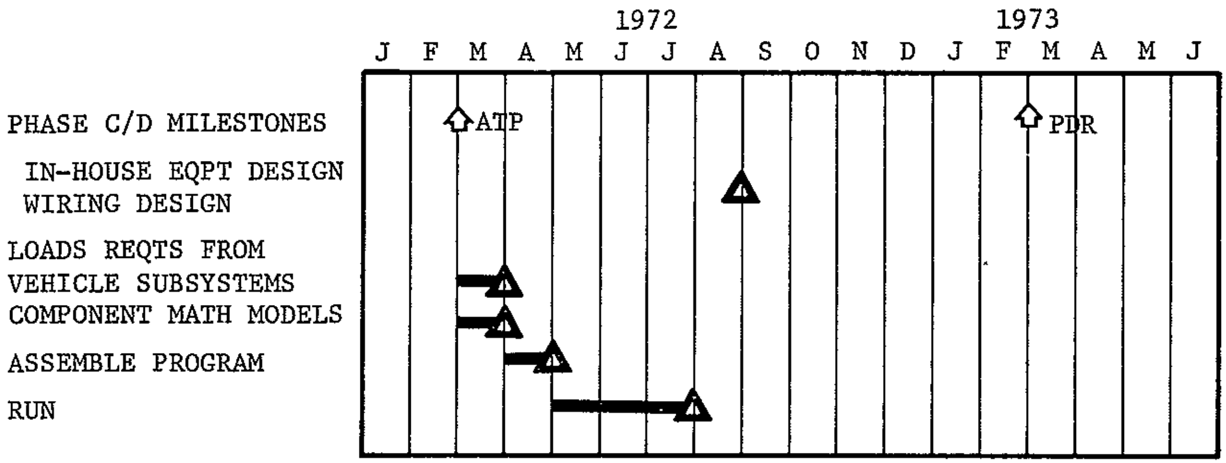


SRD 5.4.2.1.1

BOOSTER HYDRAULIC SYSTEM SIMULATION

OBJECTIVE: The objective of this simulation is to aid in design and development of the booster hydraulic power system. Output includes design data to back up preparation of system and component specifications based on design characteristics. Of primary interest are system dynamics relative to pulsation magnitudes, resonsant frequencies, handling of system transients, and system characteristics under expected loading. Analysis of these problem areas will be conducted with a computer simulation.

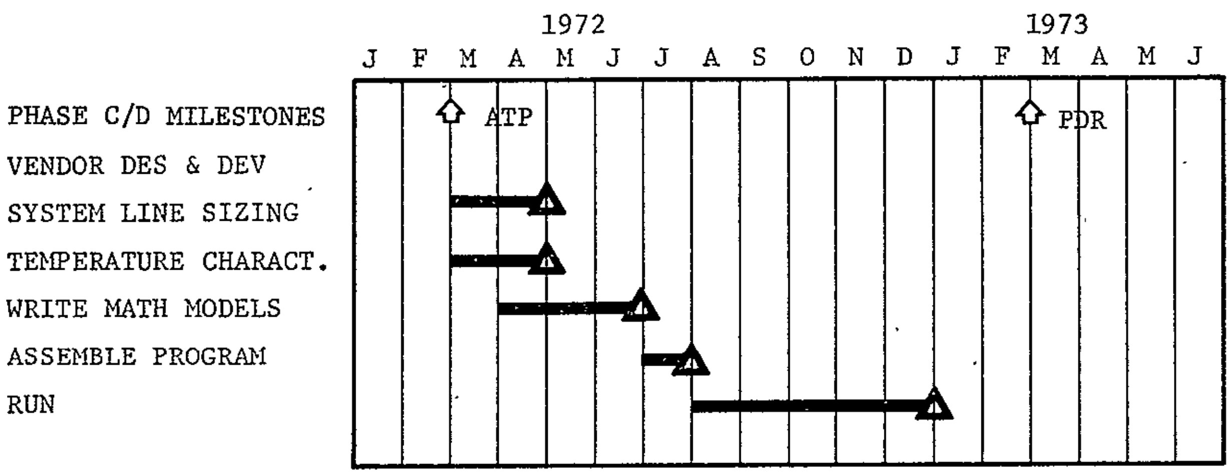
JUSTIFICATION: A computer simulation of the hydraulic system will provide a tool for analysis and solution of the system dynamics problems prior to design of prototype hardware and availability of an iron bird. Early solution of these dynamics problems results in reduced requirement for iron bird testing and prototype changes at a cost savings.

DESCRIPTION: Elements of the simulation include mathematical models of the major system components expressed in terms of rate of change of pressure and volume rate of flow. A complete system simulation should be developed with data based on preliminary design trade studies involving redundancy, reliability, cost, weight, and system power requirements. In addition to system configuration, two key data inputs resulting from computer analysis required prior to dynamic system analysis are system pressure drop characteristics (i.e., line sizes) and system operating temperatures. Evaluation of effects of hydraulic system dynamics may then be studied using the total system math model. Pump-system pulsation characteristics will be studied to assure minimum pulsation magnitudes. Pump-system resonance characteristics will be verified to be outside the pump system speed range. Interdependent "water hammer" and pump overshoot characteristics will be studied to determine optimum system configuration requirements to minimize the effects without increasing weight, cost, and maintenance requirements.

Reservoir suction line fluid acceleration characteristics must be evaluated to determine possible pump cavitation problems. Validation of total systems operation prior to hardware prototype construction will be accomplished by the system simulation.

FACILITY: No hardware or hardware interface is required. The systemm analysis is done by computer simulation. The simulation will be mechanized on a large scale computer facility with capability for higher order scientific programming languages.

SCHEDULE: Math modeling and programming should be complete by August 1972 with analysis complete by February 1973. Data from analysis should be available concurrent with vendor selection activities and prior to start of vendor design and development.



SRD 5.4.2.1.2

BOOSTER HYDRAULIC SUBSYSTEM FUNCTIONAL SIMULATION

OBJECTIVE: The objective of this task is to verify functional operation of the booster hydraulic power supply system for simulated aerodynamic portion of the mission profile. Outputs of this simulation include:

- o Verification of functional interface between hydraulic power supply system and flight control subsystem and landing system actuators
- o Verification of functional interface between data management subsystem and hydraulic flight control and landing systems
- o Verification of functional operation of hydraulic subsystem for complete mission
- o Correlation of hydraulic subsystem operation with subsystem simulation data
- o Verification that unagumented airframe response to control inputs in worst case conditions is not unstable

JUSTIFICATION: The classical Iron Bird approach to verification of hydraulic subsystem operation using actual hardware in simulated mission conditions has been singularly successful in past programs. Incorporation of all systems hardware in a simulated operating environment imparts high technical penetration to the design effort and subsequent high confidence levels. The operating subsystem occurring later in the program development provides an expedient for solution control problems which may arise.

DESCRIPTION: The following tasks related to booster vehicle subsystem development testing shall be completed prior to this simulation study.

- o Hydraulics and Controls System Test Unit facility completed and operational
- o Hydraulic actuators (Flight control system and landing system) interfaced with simulated loads
- o Hydraulic actuators interfaced with the data management system and subsystem management software is operational

System simulation shall consist of vehicle hydraulic supply system, flight control actuators, landing system actuators and simulated loads integrated into a hydraulic controls system laboratory setup. The hydraulic subsystem shall be interfaced through the data bus avionics and data management subsystem to the simulation computer which shall close the total operating system loop.

Simulation software shall include math models of vehicle equations of motion, air data, aerodynamic surface loads, simulated vehicle flight software for data management system control, and operating system for interface with the hardware portion of simulation.

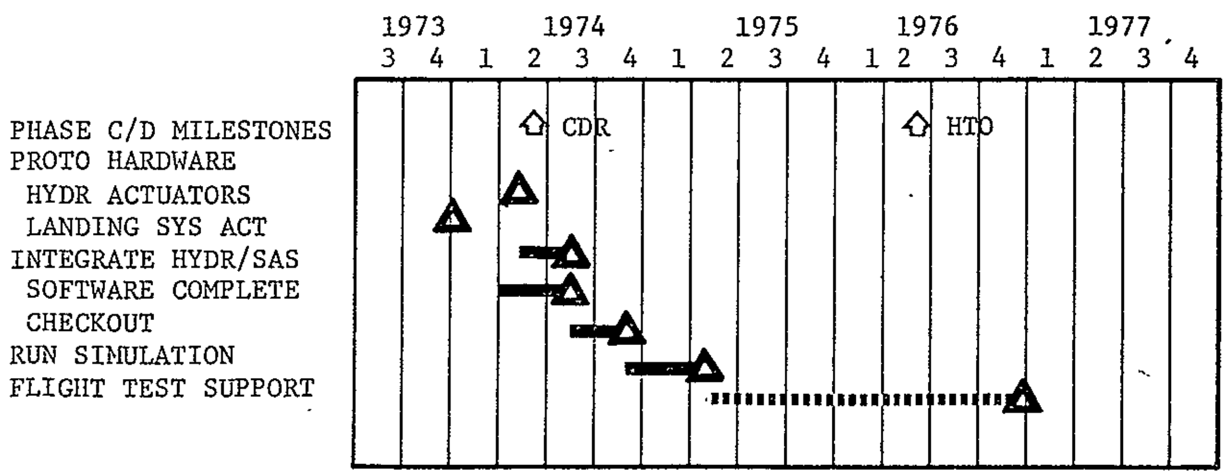
Simulation runs shall consist of a programmed aerodynamic flight mission profile from transition through landing. Transient inputs to the flight control/ landing systems shall be statistically controlled to represent worst case and normal flight and landing conditions. Functions of the hydraulic power supply system shall be monitored to determine specified operating boundaries and freedom from unusual pressure surges, pulsations, back pressures, and temperature. The second phase of this task shall consist of man-in-the-loop flight simulations to verify basic stability of the unaugmented airframe taking into account nonlinearities of flight control system hardware.

FACILITY: The following integrated facilities are required to perform this simulation:

- o Hydraulics and Controls Test Unit (HCTU) including flight control actuators, landing system actuators, and simulated aerodynamic surface inertias and dynamic loads on the flight control actuators.
- o Avionics System Test Unit (ASTU) including data management system
- o Simulation computer and hardware interfaces

Details of the HCTU and ASTU are presented in Appendix E.

SCHEDULE: This activity is dependent on availability of prototype hydraulics hardware and completion of the hydraulics and controls system test unit and avionics data management system. This task must be complete before start of flight controls subsystem verification simulations.



SRD 5.4.2.2.1

ORBITER HYDRAULIC SYSTEM SIMULATION

OBJECTIVE: The objective of this simulation is to aid in design and development of the orbiter hydraulic power system. Output includes design data to back up preparation of system and component specifications based on design characteristics. Of primary interest are system dynamics relative to pulsation magnitudes, resonsant frequencies, handling of system transients, and system characteristics under expected loading. Analysis of these problem areas will be conducted with a computer simulation.

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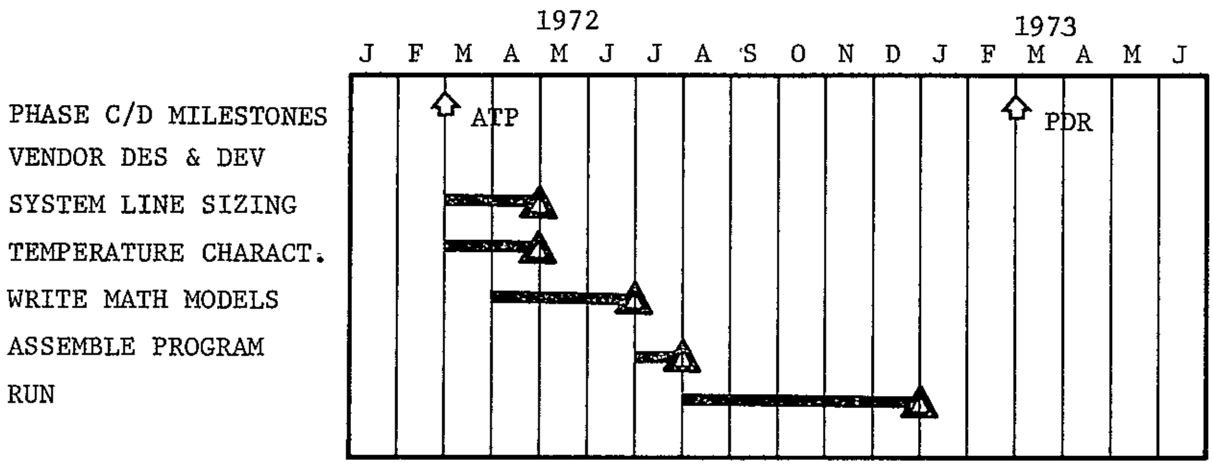
DESCRIPTION: Elements of the simulation include mathematical models of the major system components expressed in terms of rate of change of pressure and volume rate of flow. A complete system simulation should be developed with data based on preliminary design trade studies involving redundancy, reliability, cost, weight, and system power requirements. In addition to system configuration, two key data inputs resulting from computer analysis required prior to dynamic system analysis are system pressure drop characteristics (i.e., line sizes) and system operating temperatures. Evaluation of effects of hydraulic system dynamics may then be studied using the total system math model. Pump-system pulsation characteristics will be studied to assure minimum pulsation magnitudes. Pump-system resonance characteristics will be verified to be outside the pump system speed range. Interdependent "water hammer" and pump overshoot characteristics will be studied to determine optimum system configuration requirements to minimize the effects without increasing weight, cost, and maintenance requirements.

Reservoir suction line fluid acceleration characteristics must be evaluated to determine possible pump cavitation problems. Validation of total systems operation prior to hardware prototype construction will be accomplished by the system simulation.

FACILITY: No hardware or hardware interface is required. The system analysis is done by computer simulation. The simulation will be mechanized on a large scale computer facility with capability for higher order scientific programming languages.

SCHEDULE: Math modeling and programming should be complete by August 1972 with analysis complete by January 1973. Data from analysis should be available concurrent with vendor selection activities and prior to start of vendor design and development.



SRD 5.4.2.2.2

ORBITER HYDRAULIC SUBSYSTEM FUNCTIONAL SIMULATION

OBJECTIVE: The objective of this task is to verify functional operation of the orbiter hydraulic power supply system for simulated aerodynamic portion of the mission profile. Outputs of this simulation include:

- Verification of functional interface between hydraulic power supply system and flight control subsystem and landing system actuators
- Verification of functional interface between data management subsystem and hydraulic flight control and landing systems
- Verification of functional operation of hydraulic subsystem for complete mission
- Correlation of hydraulic subsystem operation with subsystem simulation data
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JUSTIFICATION: The classical Iron Bird approach to verification of hydraulic subsystem operation using actual hardware in simulated mission conditions has been singularly successful in past programs. Incorporation of all systems hardware in a simulated operating environment imparts high technical penetration to the design effort and subsequent high confidence levels. The operating subsystem occurring later in the program development provides an expedient for solution control problems which may arise.

DESCRIPTION: The following tasks related to orbiter vehicle subsystem development testing shall be completed prior to this simulation study.

- Hydraulics and Controls System Test Unit facility completed and operational
- Hydraulic actuators (Flight control system and landing system) interfaced with simulated loads
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System simulation shall consist of vehicle hydraulic supply system, flight control actuators, landing system actuators and simulated loads integrated into a hydraulic controls system laboratory setup. The hydraulic subsystem shall be interfaced through the data bus avionics and data management subsystem to the simulation computer which shall close the total operating system loop.

Simulation software shall include math models of vehicle equations of motion, air data, aerodynamic surface loads, simulated vehicle flight software for data management system control, and operating system for interface with the hardware portion of simulation.

Simulation runs shall consist of a programmed aerodynamic flight mission profile from transition through landing. Transient inputs to the flight control/landing systems shall be statistically controlled to represent worst case and normal flight and landing conditions. Functions of the hydraulic power supply system shall be monitored to determine specified operating boundaries and freedom from unusual pressure surges, pulsations, back pressures, and temperature. The second phase of this task shall consist of man-in-the-loop flight simulations to verify basic stability of the unaugmented airframe taking into account nonlinearities of flight control system hardware.

FACILITY: The following integrated facilities are required to perform this simulation:

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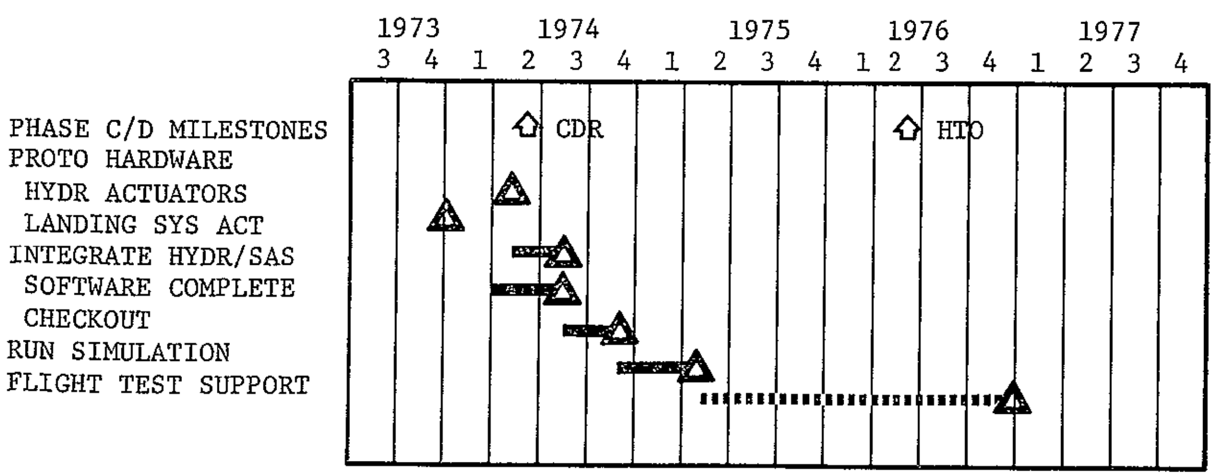
Details of the HCTU and ASTU are presented in Appendix E.

SCHEDULE: This activity is dependent on availability of prototype hydraulics hardware and completion of the hydraulics and controls system test unit and avionics data management system. This task must be complete before start of flight controls subsystem verification simulations.



SRD 6.1.1.1

BOOSTER SOFTWARE/HARDWARE VALIDATION SIMULATION

OBJECTIVE: The objective of this simulation is to validate the flight software program executing in a flight computer with real time constraints. Simulation will be performed by integrating the flight computer with flight software, fixed base cockpit simulator, all other required avionics GN&C systems (e.g. accelerometers and gimbals) with a large scale digital computer. Primary output of this simulation is verification of flight software and hardware compatibility for all vehicle systems for all mission phases.

JUSTIFICATION: This software/hardware validation simulation will be the first exercise of the flight software executing in a flight computer with actual avionics hardware in a real-time dynamic environment. Complex system integration problems with time dependent relationships are often uncovered in this type of simulation.

DESCRIPTION: Software validation will be accomplished using a hardware/software systems integration facility. The purpose of this activity is to perform a real-time execution of the flight software program in flight computer hardware under dynamic closed-loop conditions representative of actual flight. Closed-loop validation tests will be performed on flight software programs using the hardware capabilities afforded by an avionics systems test unit (ASTU) and hydraulics and controls test unit (HCTU) combined with commercial computational equipment. The software/hardware validation test configuration outlined in Figure (1) will provide the most representative execution of the flight program short of actual flight. The commerical computational equipment will be used "to close the loop" and will provide:

(1) Vehicle, environment, and sensor math models.

(2) Inputs to and accept output commands from the ASTU and HCTU hardware through the appropriate digital interface units (DIU) to affect closed loop operation.

Booster System elements to be math modeled include:

- Air Data Sensors
  - Static Pressure
  - Total Pressure
  - Total Temperature

SOFTWARE VALIDATION TEST CONFIGURATION

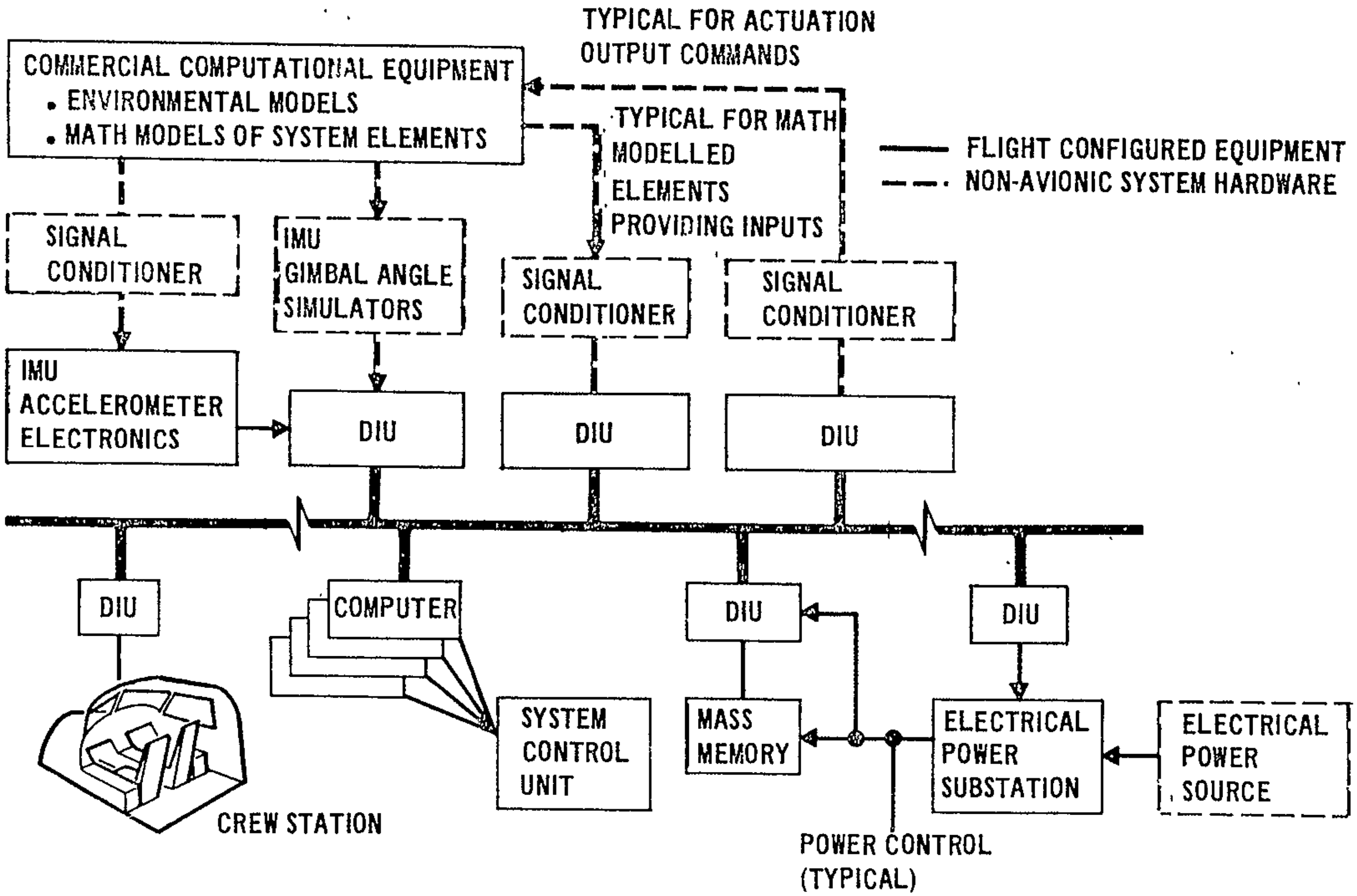


Figure (1)

- Propuslion System Elements
  - Operational Model
  - Display Data
- Communication Subsystem
- Environmental Control and Life Support Subsystem
  - Operational Model to Provide Display Data
- Landing Aids
  - VOR
  - DME
  - ILS
  - Radar Altimeter
- Rate Gyros
- Accelerometers

The selection of the actual Booster Subsystems hardware to be included in the test configuration will be made to preserve the actual system interfaces where possible and practical in the light that software validation is not meant to be a system performance evaluation. The types of actual hardware to be included are:

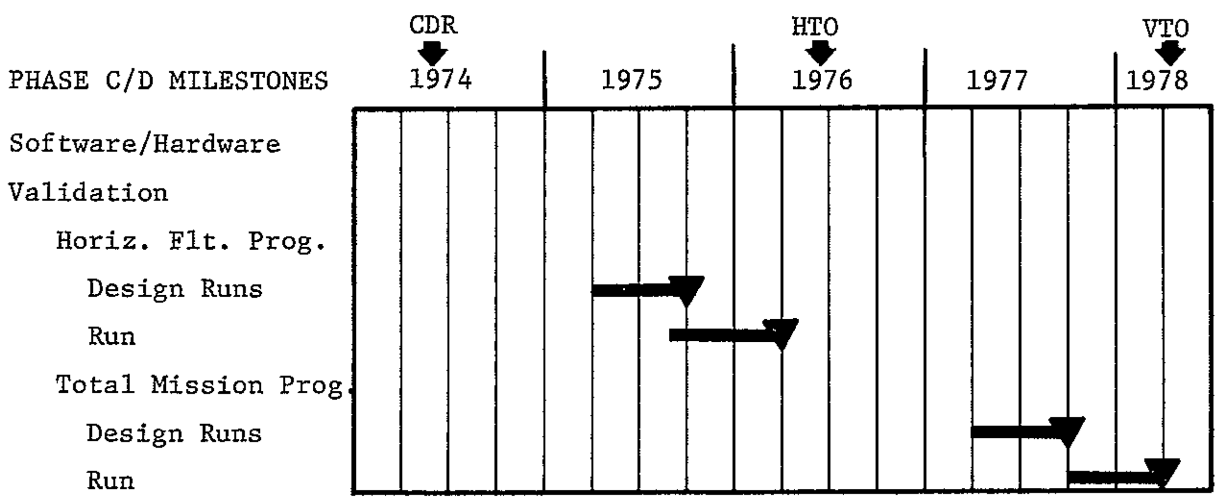
Hardware Element	Method of Data Interface
° Computer, System Control Unit and Data Bus	Actual
° Mass Memory	Actual
° Inertial Platform (Gimbal Angles)	Hardware Simulator of Interface
° Inertial Platform (Accelerometers)	Actual: Suggested Approach is to Electrically Insert Calculated Linear Acceleration Into Accelerometer Rebalance Circuitry to Obtain Corresponding Accelerometer Output Pulses
° Crew Station Controls and Displays (Items that Interface with Data Bus)	Actual
° Electrical Power	Actual for the Hardware in Simulation: Signal Conditioners for Other Power Sequence and Display Information

° Hydraulic Power (Flight Control System Actuators) — Actual (Hydraulic & Control System Test Unit)

Successful performance of this simulation requires much planning and careful definition of the environment program especially in the area of timing. The on-board computer and software will be executing in real-time. It is the responsibility of the environment program to have realistic data at the interface at the required time. The environment program will be derived by modifying the programs described in Appendix B.

FACILITY: The facility required for the simulation shall include the Systems Integration Laboratory, a large scale general purpose digital computer with standard peripherals, A/D and D/A. A fixed base booster simulator with operational instrumentation, displays and controls is also required. Description of the Systems Integration Laboratory is presented in Appendix E.

SCHEDULE: Both the horizontal flight and total mission software programs will be formally validated using customer approved validation test plans. The respective software validation testing will be completed prior to the avionic system integration verification tests.



SRD 6.1.2.1

ORBITER SOFTWARE/HARDWARE VALIDATION SIMULATION

OBJECTIVE: The objective of this simulation is to validate the flight software program executing in a flight computer with real-time constraints. Simulations will be performed by integrating the flight computer with flight software, fixed base cockpit simulator, all other required avionics GN&C systems (e.g. accelerometers and gimbals) with a large scale digital computer. Primary output of this simulation is verification of flight software and hardware compatibility for all vehicle systems for all mission phases.

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(1) Vehicle, environment, and sensor math models.

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Orbiter System elements to be math modeled include:

- Air Data Sensors
  - Static Pressure
  - Total Pressure
  - Total Temperature
- Propulsion System Elements
  - Operational Model
  - Display Data

SOFTWARE VALIDATION TEST CONFIGURATION

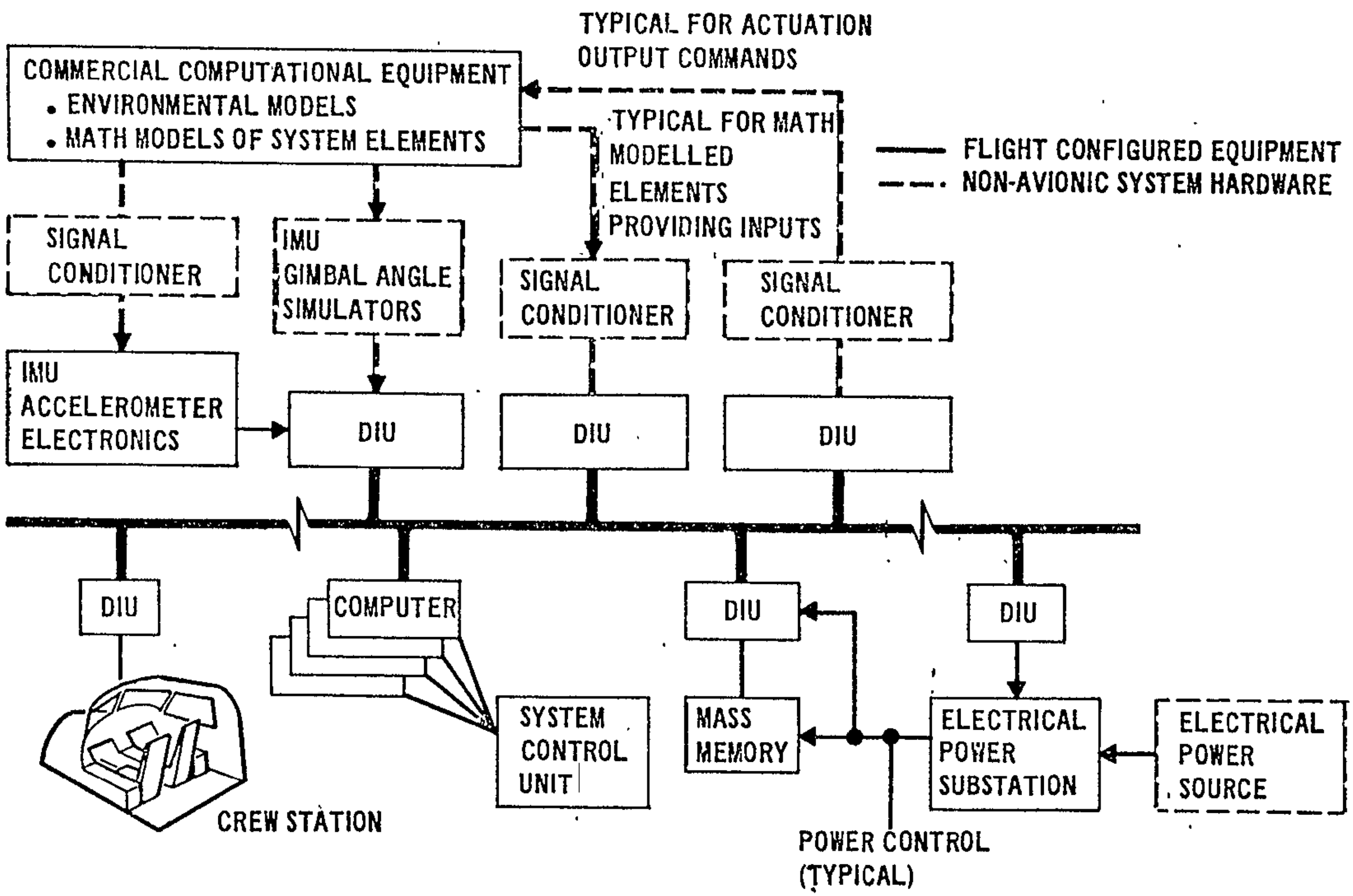

Figure (1)

- Communication Subsystem
- Environmental Control and Life Support Subsystem
  - Operational Model to Provide Display Data
- Landing Aids
  - VOR
  - DME
  - ILS
  - Radar Altimeter
- Star Tracker
- Horizon Sensor
- Rate Gyros
- Accelerometers

The selection of the actual Orbiter Subsystems hardware to be included in the test configuration will be made to preserve the actual system interfaces where possible and practical in the light that software validation is not meant to be a system performance evaluation. The types of actual hardware to be included are:

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° Inertial Platform (Gimbal Angles)	Hardware Simulator of Interface
° Inertial Platform (Accelerometers)	Actual: Suggested Approach is to Electrically Insert Calculated Linear Acceleration into Accelerometer Rebalance Circuitry to Obtain Corresponding Accelerometer Output Pulses
° Crew Station Controls and Displays (Items that Interface with Data Bus)	Actual
° Electrical Power	Actual for the Hardware in Simulation Signal Conditioners for Other Power Sequence and Display Information
° Hydraulic Power (Flight Control System Actuators)	Actual (Hydraulic & Control Systems Test Unit)

Successful performance of this simulation requires much planning and careful definition of the environment program especially in the area of timing. The on-board computer and software will be executing in real-time. It is the responsibility of the environment program to have realistic data at the interface at the required time. Some of the environment program will be derived by modifying the programs described in Appendix B.

FACILITY: The facility required for this simulation shall include the Systems Integration Laboratory, scale general purpose digital computer with standard peripherals A/D and D/A. A fixed base orbiter simulator with operational instrumentation, displays and controls is also required. Description of the Systems Integration Laboratory is presented in Appendix E.

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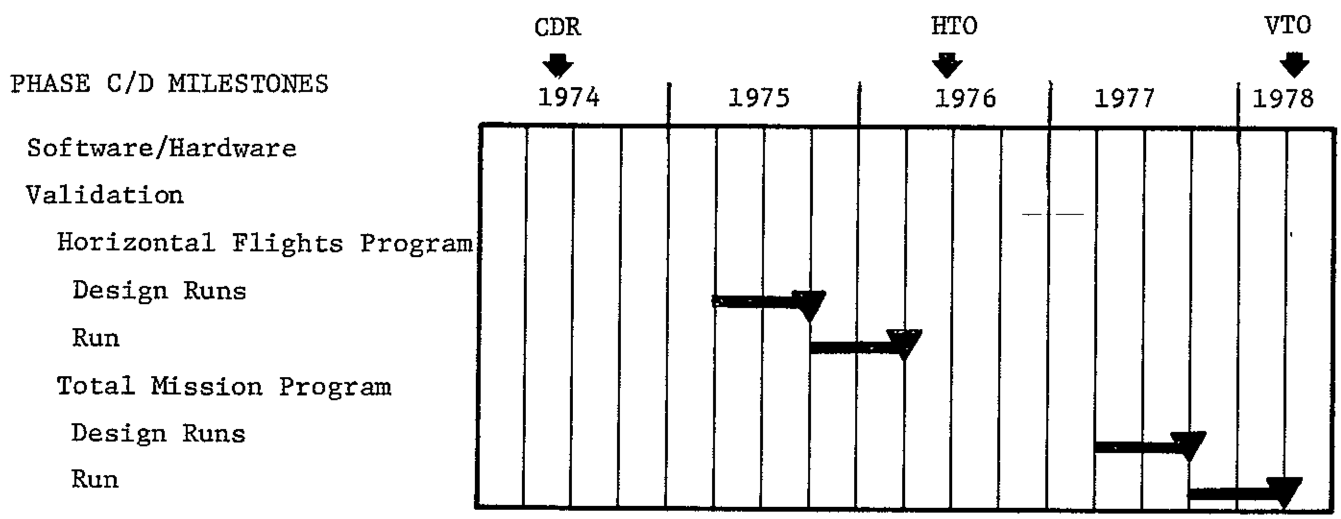


SRD 7.1.1.1

SCIENTIFIC SIMULATIONS OF BOOSTER FUNCTIONAL SOFTWARE

OBJECTIVE: The objective of these mission-phase oriented simulations is to aid in the design and verification of the functional level computer program flow diagrams. These all-digital simulations will be used to provide the following outputs:

- Evaluation of the proposed formulations and logic for on-board computer implementation
- Integration of diverse subsystems requirements
- Firm definition of onboard software requirements

JUSTIFICATION: These simulations are the final step in the design/evaluation phase prior to coding the onboard computer program. Results from these programs are used to checkout on-board computer programming. These programs are also used as "the on-board computer program" for the hybrid man-in-the-loop simulation described in Flight Mechanics SRD 1.1.1.1.2.

DESCRIPTION: Flight-worthy software is achieved by a step-by-step sequence of software verification consisting of scientific simulation, interpretive simulation, and laboratory software/hardware checkout as well as manual audits and desk analyses The scientific simulation is an all-digital representation of the total vehicle and avionics system components on a mission-phase basis. The scientific simulation will be used to verify that the integration of the various input requirements has been accomplished correctly and to provide reference data for the interpretive simulation.

The high level programming language simulations covered by this simulation requirements description provide a method of determining the effects of proposed designs and changes. These all digital simulations of the functional designs for the on-board software are used to verify the adequacy of the proposed equation formulations, accuracy and completeness of the logic statements and completeness of all interface requirements. Math models are required for all external interfaces with the functional software being simulated. These models will vary depending on the particular onboard functional flow being simulated but will include models for sensor inputs, crew inputs and, other software program inputs. These models and all other programming added to the functional simulation for input/output purposes will be modular and hence easily recognizable and separable. This is to

allow the functional simulation to be easily removed and used in other simulations (e.g. as "the onboard computer program" for the man-in-loop simulations described in SRD 1.1.1.1.2).

Checkout of the simulations covered by this description is accomplished by comparing results with data obtained using the applicable six-degree-of-freedom simulation described in SRD 4.1.1.4 (Closed-loop Performance Analysis).

The reference environment math models for the simulations covered by this description are listed in Appendix B. Math models are required to interface between the reference environment and functional flow simulations to provide data representative of the following avionics hardware sensors:

- IMU
- Rate gyros
- Body mounted accelerometers
- Radar altimeter
- VOR/DME
- ILS and glidescope
- Air data instrumentation
- Ranging sensor
- ATC transponder

Simulations covered by this simulation requirements description are required for the following onboard computer program modules:

- Central module
- Navigation module
- Ascent module
- Reentry module
- Landing module
- Off-line utility modules
  - Prelaunch targeting
  - Cruise route selection
  - Retrograde time determination
  - IMU calibration
  - IMU alignment
  - Prelaunch fuel loading
  - Ferry guidance

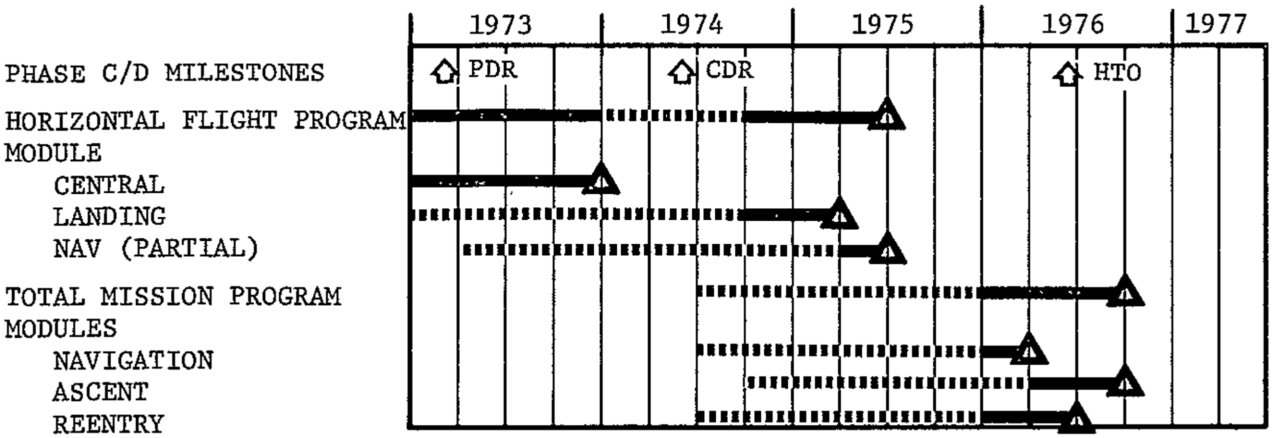
The functions provided by the on-line modules are:

Module	Functions
Central	° Master Executive
	° Data Bus Control
	° Mass Memory Control
	° Reconfiguration Management
	° Sensor Processing
	° Display and Control
	° Computational Subroutines
	° On-orbit Attitude and Translation Flight Control
	° On-Avionics Subsystem Servicing
Navigation	° Powered Flight Mode
	° Coast Mode
	° Autonomous State Vector Update
	° Relative Motion
	° Ground Aided
Ascent	° Ascent Guidance Mode
	° Ascent-abort Guidance Mode
	° Main Engine Thrust Command
	° Main Engine Gimbal Control
	° Main Engine Propulsion Monitoring
Reentry	° Reentry Guidance
	° Reentry Flight Control
Landing	° Terminal Area Guidance
	° Aerodynamic Flight Control

FACILITY: These simulations will execute on any general purpose digital computer with standard peripherals.

SCHEDULE: The development of these scientific simulations is an iterative process starting with requirements defined, in part, by outputs from simulations described in Flight Mechanics SRD 4.1.1.1, 4.1.1.2, 4.1.1.3 and 4.1.1.4. Consequently, activity on developing the simulations covered by this description is shown commencing near the end of activities on flight mechanics digital simulation. The milestones on the schedule represent the point in time when

onboard computer program coding specification for the indicated program module is to be available.



SRD 7.1.1.2

BOOSTER ONBOARD COMPUTER SIMULATION

OBJECTIVE: The objective of this simulation is to provide a software tool to enhance the capabilities for checkout of onboard computer programming. Outputs from this interpretive simulation are used to enable:

- o Verification of onboard computer program coding accuracy.
- o Evaluation of accuracy of complete functions
- o Verification of adequacy of onboard computer program interfaces
- o Evaluation of onboard software capability to satisfy mission requirements.

JUSTIFICATION: This simulation allows onboard software to be checked out in static and pseudo-dynamic, (i.e. not real time), check cases without requiring use of an onboard computer. The more flexible output capabilities of this simulation greatly enhance the debugging operations.

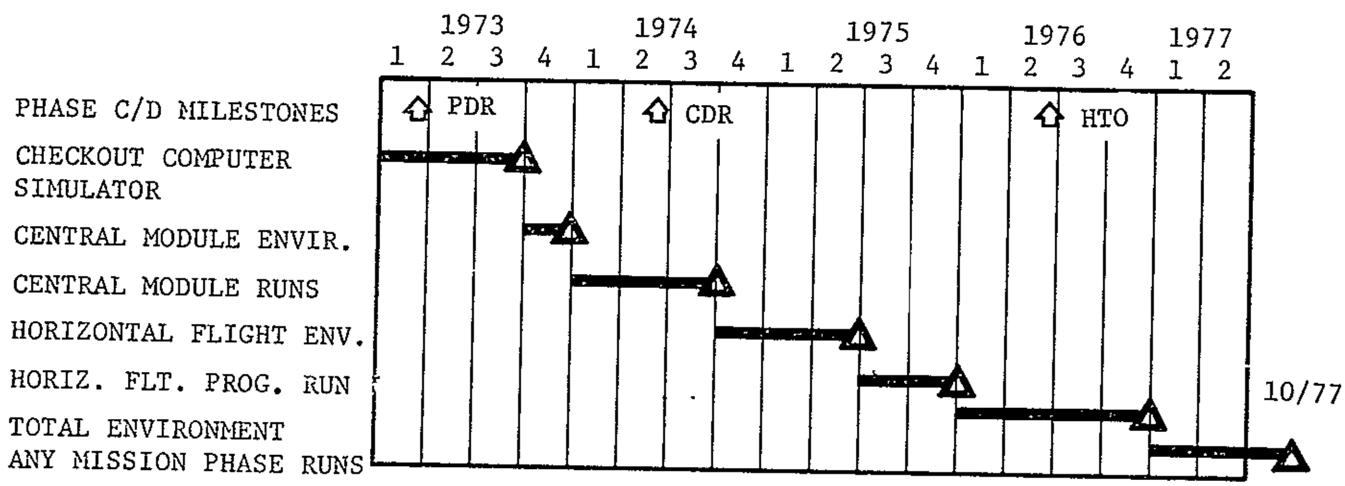
DESCRIPTION: The interpretive simulation (onboard computer simulator) is a basic software tool and provides the means to accomplish program debug of the coded program to perfom another level of program verification. The onboard computer simulator accepts the output of the assembly or compiler, interprets the code and executes the operation providing a bit for bit correspondence with actual onboard computer execution. The simulator program will execute on a large scale commercial computer and will provide extensive input/output and debugging aids.

Four types of simulations using the interpretive simulation are anticipated. The first is a static simulation which is a single pass through a portion of a program with known static inputs to yield expected outputs. This simulation provides verification of coding accuracy with respect to equation formulation. The second type of simulation is open-loop with inputs provided by a user supplied environment program. This type of simulation is used to verify a complete function or subroutine and is capable of determining the accuracy over the entire range of input data values. The third type of simulation is closed-loop with inputs provided by a user supplied environment. This type of simulation is used primarily to verify dynamic communications between the interfacing computer subprograms, subroutines and programs. The fourth type of simulation using the interpretive simulator is closed-loop with realistic mission phase inputs being provided by a user supplied reference environment program (See Appendix B). This type of simulation is used to verify that the onboard software performs all required functions for a successful mission but without real time constraints.

The onboard computer simulator requires math models for the repertoire of instructions, operations and commands. These math models must be totally faithful, i.e., provide exact bit for bit results as the onboard computer, but need not operate with the identical timing. Models are also required for the memory, computer clock and input/output.

FACILITY: A large scale general purpose digital computer with standard complement of peripherals is required for this simulation.

SCHEDULE: Use of the simulator to checkout flight software is scheduled to begin by the first quarter of 1974.



SRD 7.1.2.1

SCIENTIFIC SIMULATIONS OF ORBITER FUNCTIONAL SOFTWARE

OBJECTIVE: The objective of these mission phase oriented simulations is to aid in the design and verification of the functional level computer program flow diagrams. These all-digital simulations will be used to provide the following outputs:

- o Evaluation of the proposed formulations and logic for onboard computer implementation
- o Integration of diverse subsystems requirements
- o Firm definition of onboard software requirements

JUSTIFICATION: These simulations are the final step in the design/evaluation phase prior to coding the onboard computer program. Results from these programs are used to checkout onboard computer programming. These programs are also used as "the onboard computer program" for the hybrid man-in-the-loop simulation described in Flight Mechanics SRD 1.1.1.2.2.

DESCRIPTION: Flight-worthy software is achieved by a step-by-step sequence of software verification consisting of scientific simulation, interpretive simulation, and laboratory software/hardware checkout as well as manual audits and desk analyses. The scientific simulation is an all-digital representation of the total vehicle and avionics system components on a mission phase basis. The scientific simulation will be used to verify that the integration of the various input requirements has been accomplished correctly and to provide reference data for the interpretive simulation.

The high level programming language simulations covered by this simulation requirements description provide a method of determining the effects of proposed designs and changes. These all digital simulations of the functional designs for the onboard software are used to verify the adequacy of the proposed equation formulations, accuracy and completeness of the logic statements and completeness of all interface requirements. Math models are required for all external interfaces with the functional software being simulated. These models will vary depending on the particular onboard functional flow being simulated but will include models for sensor inputs, crew inputs and other software program inputs. These models and all other programming added to the functional simulation for input/output purposes will be modular and hence easily recognizable and separable.

This is to allow the functional simulation to be easily removed and used in other simulations (e.g. as "the onboard computer program" for the man-in-loop simulations described in SRD 1.1.1.2.2).

Checkout of the simulations covered by this description is accomplished by comparing results with data obtained using the applicable six-degree-of-freedom simulation described in SRD 4.1.2.4 (closed-loop performance analysis).

The reference environment math models for the simulations covered by this description are listed in Appendix (B). Math models are required to interface between the reference environment and functional flow simulations to provide data representative of the following avionics hardware sensors:

- o IMU
- o Rate gyros
- o Body mounted accelerometers
- o Horizon scanner
- o Star tracker
- o Radar altimeter
- o VOR/DME
- o ILS and glideslope
- o Air data instrumentation
- o Ranging sensor

Simulations covered by this simulation requirements description are required for the following onboard computer program modules:

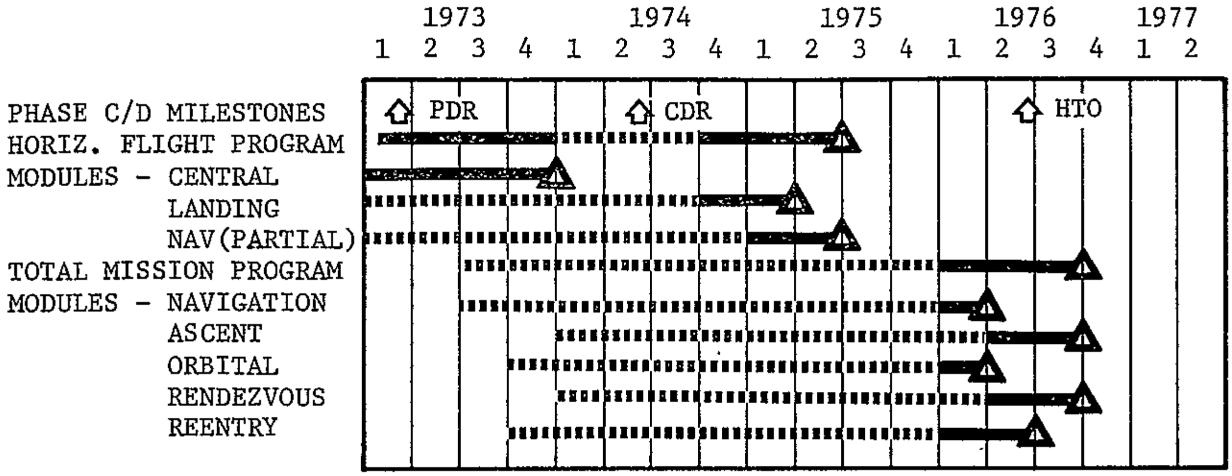
- o Central module
- o Navigation module
- o Ascent module
- o Orbital phasing module
- o Rendezvous module
- o Reentry Module
- o Landing module
- o Off-line utility modules
    - o Prelaunch targeting
    - o Cruise route selection
    - o Retrograde time determination
    - o IMU calibration
    - o Prelaunch fuel loading
    - o Ferry guidance

The functions provided by the on-line modules are:

Module	Functions
Central	o Master Executive o Data bus control o Mass Memory Control o Reconfiguration management o Sensor Processing o Display and control o Computational Subroutines o On-orbit attitude and translation flight control o On-Avionics subsystem servicing
Navigation	o Powered flight mode o Coast Mode o Autonomous state vector update o Relative motion o Ground aided
Ascent	o Ascent guidance mode o Ascent-abort guidance mode o Main engine thrust command o Main engine gimbal control o Main engine propulsion monitoring
Orbital Phasing	o Phasing maneuver determination and execution mode
Rendezvous Module	o Rendezvous o Docking o Station keeping
Reentry	o Reentry guidance o Reentry flight control
Landing	o Terminal area guidance o Aerodynamic flight control

FACILITY: These simulations will execute on any general purpose digital computer with standard peripherals.

SCHEDULE: The development of these scientific simulations is an iterative process starting with requirements defined, in part, by outputs from simulations described in Flight Mechanics SRD 4.1.2.1, 4.1.2.2, 4.1.2.3 and 4.1.2.4. Consequently, activity on developing the simulations covered by this description is shown commencing near the end of activities on flight mechanics digital simulation. The milestones on the schedule represent the point in time when onboard computer program coding specification for the indicated program module is to be available.


1973
1974
1975
1976
1977
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2
PDR
CDR
HTO
PHASE C/D MILESTONES
HORIZ. FLIGHT PROGRAM
MODULES - CENTRAL
LANDING
NAV (PARTIAL)
TOTAL MISSION PROGRAM
MODULES - NAVIGATION
ASCENT
ORBITAL
RENDEZVOUS
REENTRY

SRD 7.1.2.2

ORBITER ONBOARD COMPUTER SIMULATION

OBJECTIVE: The objective of this simulation is to provide a software tool to enhance the capabilities for checkout of onboard computer programming. Outputs from this interpretive simulation are used to enable:

- o Verification of onboard computer program coding accuracy
- o Evaluation of accuracy of complete functions
- o Verification of adequacy of onboard computer program interfaces
- o Evaluation of onboard software capability to satisfy mission requirements.

JUSTIFICATION: This simulation allows onboard software to be checked out in static and pseudo-dynamic, (i.e. not real time), check cases without requiring use of an onboard computer. The more flexible output capabilities of this simulation greatly enhance the debugging operations.

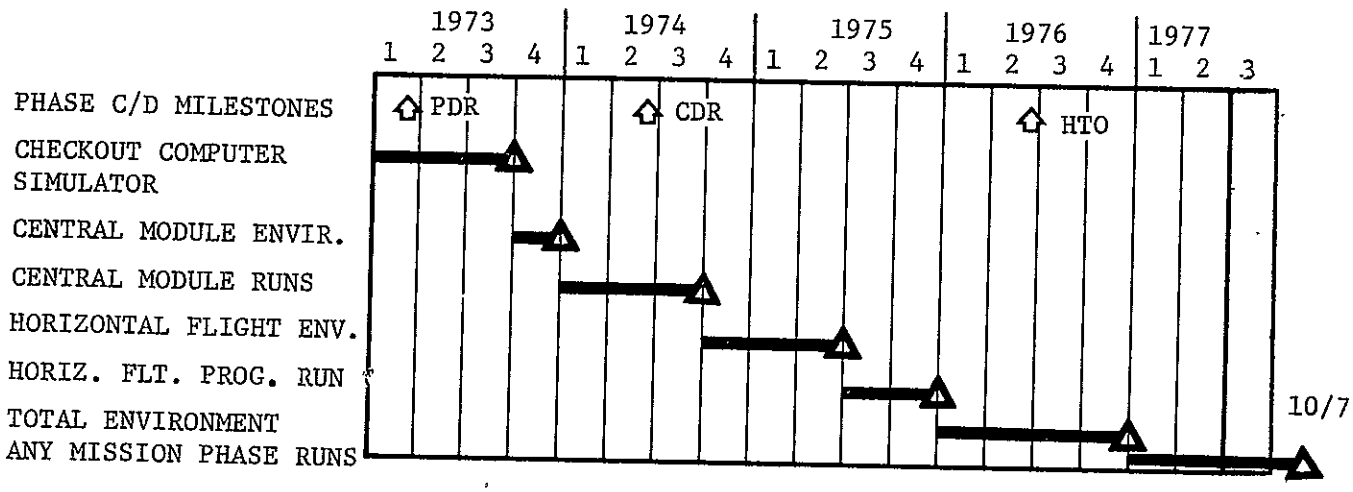
DESCRIPTION: The interpretive simulation (onboard computer simulator) is a basic software tool and provides the means to accomplish program debug of the coded program to perfom another level of program verification. The onboard computer simulator accepts the output of the assembly or compiler, interprets the code and executes the operation providing a bit for bit correspondence with actual onboard computer execution. The simulator program will execute on a large scale commercial computer and will provide extensive input/output and debugging aids.

Four types of simulations using the interpretive simulation are anticipated. The first is a static simulation which is a single pass through a portion of a program with known static inputs to yield expected outputs. This simulation provides verification of coding accuracy with respect to equation formulation. The second type of simulation is open-loop with inputs provided by a user supplied environment program. This type of simulation is used to verify a complete function or subroutine and is capable of determining the accuracy over the entire range of input data values. The third type of simulation is closed-loop with inputs provided by a user supplied environment. This type of simulation is used primarily to verify dynamic communications between the interfacing computer subprograms, subroutines and programs. The fourth type of simulation using the interpretive simulator is closed-loop with realistic mission phase inputs being provided by a user supplied reference environment program (See Appendix B). This type of simulation is used to verify that the onboard software performs all required functions for a successful mission but without real time constraints.

The onboard computer simulator requires math models for the repertoire of instructions, operations and commands. These math models must be totally faithful, i.e., provide exact bit for bit results as the onboard computer, but need not operate with the identical timing. Models are also required for the memory, computer clock and input/output.

FACILITY: A large scale general purpose digital computer with standard complement of peripherals is required for this simulation.

SCHEDULE: Use of the simulator to checkout flight software is scheduled to begin by the first quarter of 1974.



SRD 8.1.1

BOOSTER VEHICLE TO GROUND CHECKOUT INTERFACE VERIFICATION

OBJECTIVE: The objective of this task is to provide a means for verifying ground based test and checkout equipment and procedures through the use of simulation techniques. A real-time all digital simulation of booster vehicle subsystems operation during pre-launch and post-flight phases shall be developed to interface with ground complex equipment. Outputs of this task shall be:

- o Verification of ground complex interface compatibility with vehicle data management system and onboard checkout system
- o Development of pre-launch checkout software and procedures from the ground complex standpoint (i.e., augmenting onboard checkout operations and fault isolation)
- o Aid in defining ground complex requirements in terms of personnel and equipment
- o Development of support software and procedures during countdown and launch function
- o Development of support software and procedures for post launch maintenance and analysis function.

JUSTIFICATION: The ground checkout computer software programs and checkout procedures should be verified through simulation rather than interfacing with the actual flight vehicle. The simulation method represents a direct cost savings and allows parallel development of ground test and checkout systems and procedures independent of vehicle hardware availability. By developing all-software simulation, costs associated with hardware simulator development may be eliminated.

DESCRIPTION: System configuration shall consist of a simulation computer interfaced through actual or simulated vehicle data bus hardware with the actual ground complex monitor/control units and computers. The simulation computer shall represent the booster vehicle by providing simulated real-time subsystems signal traffic through the data bus interface with the ground support equipment. Although the simulation shall be designed to execute in real-time, strict timing details may be minimized in the interest of a cost effective programming effort. Math models of vehicle subsystems shall be adopted from subsystems development data. Applicable flight software modules to be simulated include:

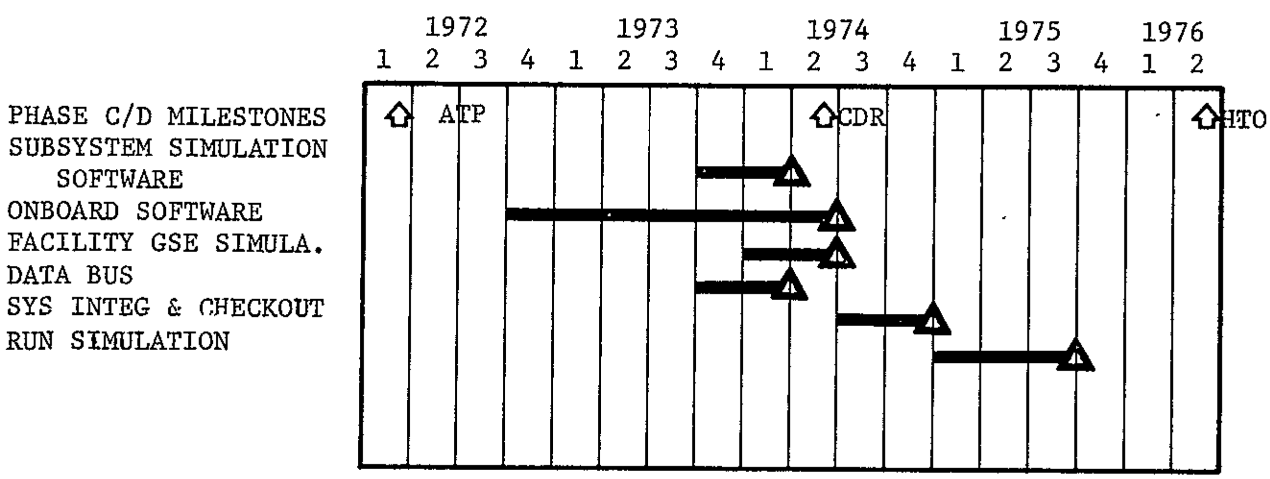
- o Executive
- o Data Bus Control
- o Redundancy Management

- o Subsystem Sequencing
- o Prelaunch Targeting
- o IMU Calibration & Alignment
- o Sensor Processing
- o Subsystem Checkout
- o Mass Memory
- o Display and Controls
- o Prelaunch Fuel Loading

A programmable fault insertion module shall be implemented in the simulation computer to the extent required to adequately exercise the ground complex fault isolation routines. The simulation computer shall provide functional simulation of ground facilities that interface with the ground checkout complex through the GSE data bus.

FACILITY: The facility required is a digital computer and associated peripheral equipment. The digital computer shall be capable of being programmed in a higher order language. Hardware interface requirements include four redundant vehicle data busses and one GSE facility data bus.

SCHEDULE: The simulation shall be run when GSE equipment, ground checkout software, and onboard software is available.



SRD 8.1.2

BOOSTER SUPPORTABILITY ANALYSIS

OBJECTIVE: The objective of this analysis is the use of simulation techniques to analyze and integrate mission support functions. Mission support functions are defined as those functions not directly involved with the performance of the mission task. This math model represents the flow of activity related to prelaunch and post launch maintenance and refurbishment functions. The simulation model shall be capable of determining the following:

- o Sources and criticality of delays involved in support functions
- o Proper utilization of support functions
- o Cost involved in support functions
- o Measurement of support function performance

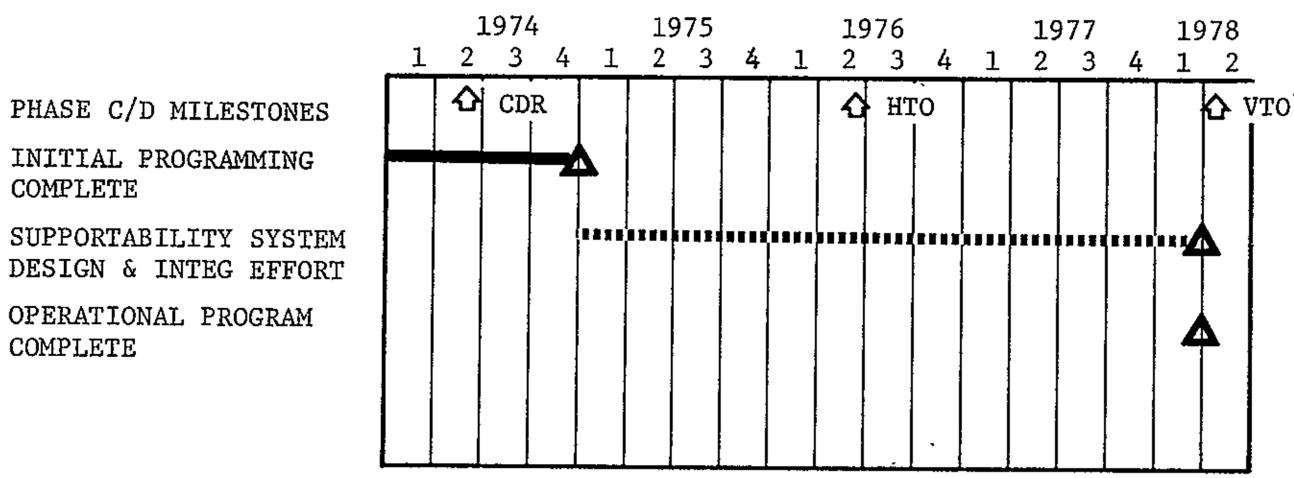
JUSTIFICATION: The frequency of launches and resulting short turn around times require an efficient support organization to minimize cost. Application of operations research simulation techniques to evaluate support system organization and procedures is a cost effective means of controlling expense.

DESCRIPTION: The supportability operations model represents the enviornment of space shuttle support operations as an end-to-end simulation of the post launch to prelaunch maintenance and refurbishment cycle. The supportability model consists of the operations submodel, maintenance submodel and data base. The operations submodel represents the interface of the support system with the overall mission operations. Only those mission functions related to support operations are modeled as other aspects of mission operations are not pertinent to supportability. Maintenance function can be considered the major influence on shuttle supportability operations, therefore supply and transportation shall be treated in a purely deterministic manner within the maintenance subprogram. The data base will include resources consisting of people, equipment, facilities, and parts inventories. Activities to be model under maintenance function include corrective and preventive maintenance of the booster vehicle, main engines and LRU items, and post maintenance inspection and verification testing. The submodels shall be mechanized in a modern simulation language capable of stochastic solutions to the problems of resource allocations in supportability operations. Thorough evaluation of existing simulation languages is required to determine the language best suited for this application. Selection of a language is beyond the scope of this SRD.

Supportability simulation during Phase C/D shall be used to assist in planning and analysis of the maintenance function to be performed during shuttle operations. The supportability operations simulation shall be used during post Phase C/D operations to assure proper utilization of support functions and aid in control of operating costs.

FACILITY: This simulation requires a large scale scientific digital computer with mass storage capability. The computer facility size and type is dependent on simulation language used.

SCHEDULE: Operational program should be completed by end of 1974. Periodic revisions will be incorporated throughout Phase C/D. Program should be in its final form by end of Phase D.



SRD 8.2.1

ORBITER VEHICLE TO GROUND CHECKOUT INTERFACE VERIFICATION

OBJECTIVE: The objective of this task is to provide a means for verifying ground based test and checkout equipment and procedures through the use of simulation techniques. A real-time all digital simulation of orbiter vehicle subsystems operation during pre-launch and post-flight phases shall be developed to interface with ground complex equipment. Outputs of this task shall be:

- o Verification of ground complex interface compatibility with vehicle data management system and onboard checkout system
- o Development of pre-launch checkout software and procedures from the ground complex standpoint (i.e., augmenting onboard checkout operations and fault isolation)
- o Aid in defining ground complex requirements in terms of personnel and equipment
- o Development of support software and procedures during countdown and launch function
- o Development of support software and procedures for post launch maintenance and analysis function.

JUSTIFICATION: The ground checkout computer software programs and checkout procedures should be verified through simulation rather than interfacing with the actual flight vehicle. The simulation method represents a direct cost savings and allows parallel development of ground test and checkout systems and procedures independent of vehicle hardware availability. By developing all-software simulation, costs associated with hardware simulator development may be eliminated.

DESCRIPTION: System configuration shall consist of a simulation computer interfaced through actual or simulated vehicle data bus hardware with the actual ground complex monitor/control units and computers. The simulation computer shall represent the booster vehicle by providing simulated real-time subsystems signal traffic through the data bus interface with the ground support equipment. Although the simulation shall be designed to execute in real-time, strict timing details may be minimized in the interest of a cost effective programming effort. Math models of vehicle subsystems shall be adopted from subsystems development data. Applicable flight software modules to be simulated include:

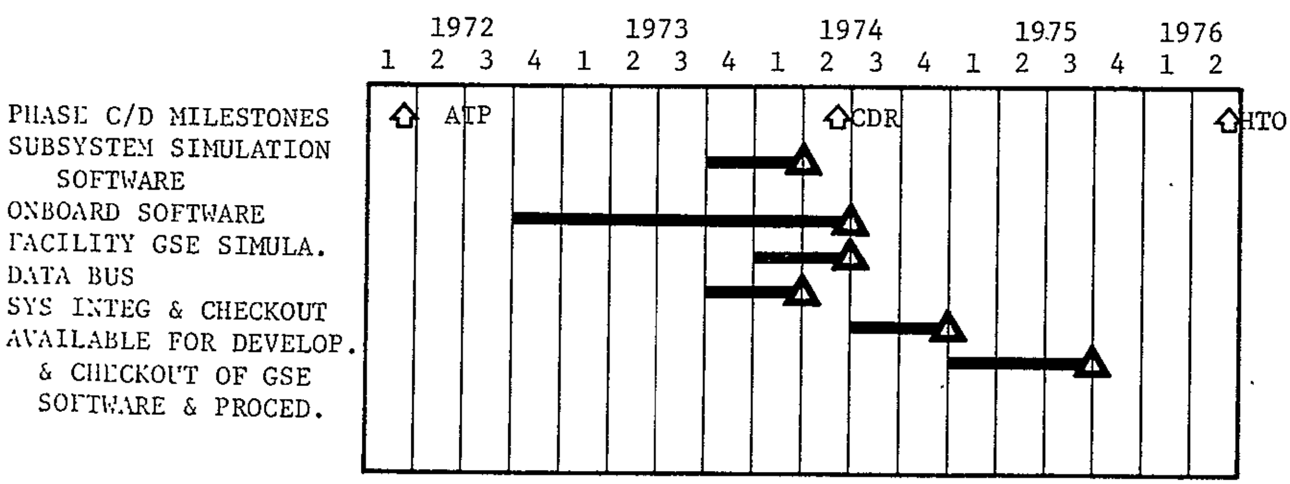
- o Executive
- o Data Bus Control
- o Redundancy Management

- o Subsystem Sequencing
- o Prelaunch Targeting
- o IMU Calibration & Alignment
- o Sensor Processing
- o Subsystem Checkout
- o Mass Memory
- o Display and Controls
- o Prelaunch Fuel Loading

A programmable fault insertion module shall be implemented in the simulation computer to the extent required to adequately exercise the ground complex fault isolation routines. The simulation computer shall provide functional simulation of ground facilities that interface with the ground checkout complex through the GSE data bus.

FACILITY: The facility required is a digital computer and associated peripheral equipment. The digital computer shall be capable of being programmed in a higher order language. Hardware interface requirements include four redundant vehicle data busses and one GSE facility data bus.

SCHEDULE: The simulation shall be run when GSE equipment, ground checkout software, and onboard software is available.



SRD 8.2.2
ORBITER SUPPORTABILITY ANALYSIS

OBJECTIVE: The objective of this analysis is the use of simulation techniques to analyze and integrate mission support functions. Mission support functions are defined as those functions not directly involved with the performance of the mission task. This math model represents the flow of activity related to prelaunch and post launch maintenance and refurbishment functions. The simulation model shall be capable of determining the following:

- o Sources and criticality of delays involved in support functions
- o Proper utilization of support functions
- o Cost involved in support functions
- o Measurement of support function performance

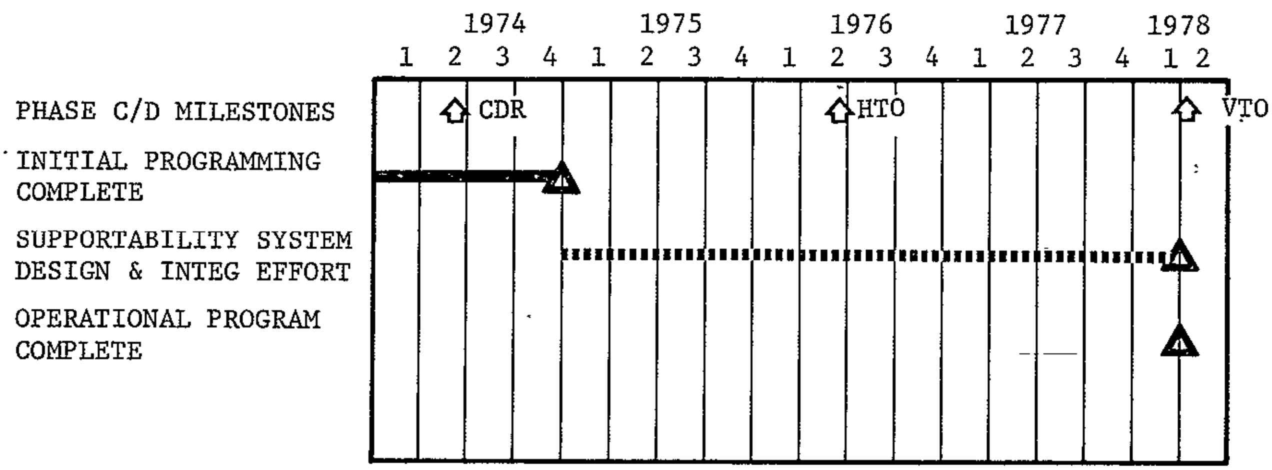
JUSTIFICATION: The frequency of launches and resulting short turn around times require an efficient support organization to minimize cost. Application of operations research simulation techniques to evaluate support system organization and procedures is a cost effective means of controlling expense.

DESCRIPTION: The supportability operations model represents the enviornment of space shuttle support operations as an end-to-end simulation of the post launch to prelaunch maintenance and refurbishment cycle. The supportability model consists of the operations submodel, maintenance submodel and data base. The operations submodel represents the interface of the support system with the overall mission operations. Only those mission functions related to support operations are modeled as other aspects of mission operations are not pertinent to supportability. Maintenance function can be considered the major influence on shuttle supportability operations, therefore supply and transportation shall be treated in a purely deterministic manner within the maintenance subprogram. The data base will include resources consisting of people, equipment, facilities, and parts inventories. Activities to be model under maintenance function include corrective and preventive maintenance of the orbiter vehicle, booster vehicle, main engines and LRU items, and post maintenance inspection and verification testing. The submodels shall be mechanized in a modern simulation language capable of stochastic solutions to the problems of resource allocations in supportability operations. Thorough evaluation of existing simulation languages is required to determine the language best suited for this application. Selection of a language is beyond the scope of this SRD.

Supportability simulation during Phase C/D shall be used to assist in planning and analysis of the maintenance function to be performed during shuttle operations. The supportability operations simulation shall be used during post Phase C/D operations to assure proper utilization of support functions and aid in control of operating costs.

FACILITY: This simulation requires a large scale scientific digital computer with mass storage capability. The computer facility size and type is dependent on simulation language used.

SCHEDULE: Operational program should be completed by end of 1974. Periodic revisions will be incorporated throughout Phase C/D. Program should be in its final form by end of Phase D.



SRD 8.3.1

MISSION OPERATIONS ANALYSIS

OBJECTIVE: The objective of this analysis is to use simulation techniques to evaluate the effect of integrated events and resources on total mission operations. The simulation may be used to optimize mission operations based on given manpower, facilities, time, and cost restraints. The simulation will display effects on mission operations resulting from decisions involving projected changes in manpower, facilities, or mission goals. Impact of unforeseen delays on the mission schedule may be studied and alternative plans developed.

JUSTIFICATION: The simulation program is a powerful operations research tool for analyzing events, time constraints, manpower, and resources that react stochastically to requirements changes. The simulation assists management in making decisions that would maximize cost effectiveness. The simulation particularly lends itself to the multiple vehicle and multiple launch requirements of Space Shuttle and can provide data for decision making that would be costly and time consuming to obtain through manual means.

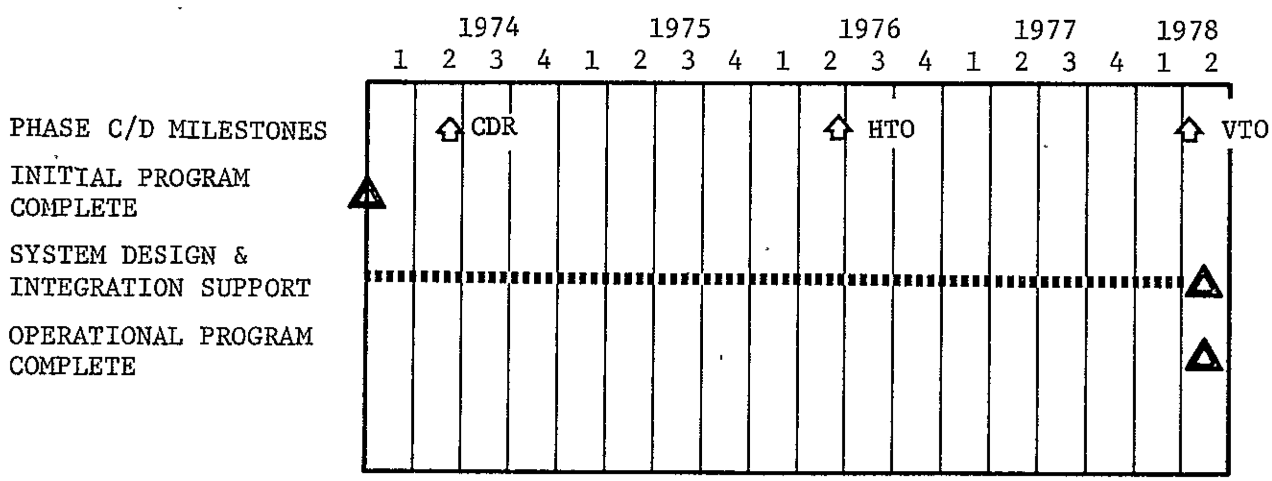
DESCRIPTION: The mission operations model represents the environment of the Space Shuttle as a closed-loop sequence of operations consisting of all booster and orbiter vehicles involved in flight and ground operation activities. Subprograms describing payload resources and requirements and space station operations shall be incorporated as expansions of the basic shuttle operations model.

The mission operations model consists of two basic parts, a data base and operational network model. Resources involving available people, equipment facilities, and supplies reside in the data base. These resources represent constraints to the network model. The network model represents interrelated activities involved in mission operations. These activities include launch operations, flight operations, post flight operations, refurbishment and maintenance operations, booster and orbiter mating, and pre-flight checkout. The operations network shall be modeled in a high-level simulation language capable of stochastic solutions to the problems of allocating manpower and resources in mission operations. A thorough evaluation of existing simulation languages is required to determine which one is best suited for this application. Although selection of a language is beyond the scope of this SRD, a number of choices are available for the user (e.g., SIMSCRIPT, SIMULA, GPSS, GASP, ACTNET, etc.). This

simulation shall have application during phase C/D development and during post phase C/D operations. During phase C/D, the simulation shall be used to analyze and improve operations scheduling activity based on vehicle, payload, and ground support equipment design data. Potential operations problems shall be isolated and solved. During post phase C/D (operations phase) the simulation shall be used to evaluate the impact of alternative decisions and provide data for decision making in the event of unscheduled delays or activities.

FACILITY: This simulation requires a large scale digital computer with mass storage capability. The computer facility size and type is dependent on simulation language used.

SCHEDULE: Operational program should be completed by end of 1973. Periodic revisions will be incorporated throughout phase C/D. Program should be in its final form by end of phase D. Simulation will aid in systems design and integration of mission operations during phase C/D and will serve as a decision making aid during operational phase.



SRD 8.3.2

FUEL LOADING PROCESS MANAGEMENT SIMULATION

OBJECTIVE: The purpose of this simulation is to aid in developing automatic control system used in the fuel loading process. Outputs from this simulation will be in the form of:

- Definition of software requirements
- Definition of data interface with GSE computer program
- Definition of procedures for automatic control of fuel loading process

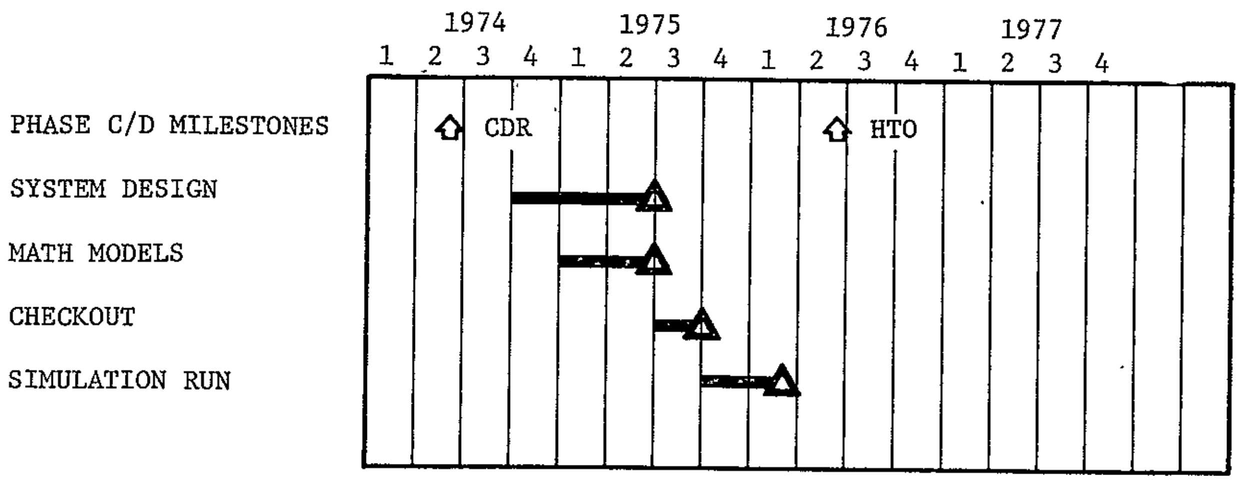
JUSTIFICATION: This simulation is required to develop both onboard and GSE computer programs requirements, and hardware system to be used in fuel loading. As with any automatic system, computer simulation affords an excellent method of verifying total system operation and enables design optimization of interacting elements.

DESCRIPTION: The fuel loading process management simulation program will include models of four participating systems. These are the ground fuel loading and supply system, and ground computer program, the onboard computer program and the onboard fuel system.

The ground and onboard fuel system models will include tanks, interconnecting pipes, valves, pressure regulators, and sensors as required to provide a realistic and meaningful simulation of the process. The critical parameters will be defined for automatic monitoring by the software programs. These will include pressures, flow rates, fuel volumes and leak detection.

FACILITY: A general purpose digital computer with standard peripherals will be required for this simulation.

SCHEDULE: This simulation should be performed sufficiently early so as to be beneficial to GSE design development. First use of actual fuel loading program will be at VTOM (March 1978).


1974
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1976
1977
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
PHASE C/D MILESTONES
CDR
HTO
SYSTEM DESIGN
MATH MODELS
CHECKOUT
SIMULATION RUN

APPENDIX B

SUMMARY OF ALTERNATE SIMULATION PLANS

These tables represent a summary of two alternate simulation plans formulated for the Booster and Orbiter. Plan I represents a plan in which technical risk is minimized through deep technical penetration using multiple simulation activities in NASA and industry. Plan II represents adequate technical penetration to support critical design and integration areas through eliminating non-critical simulations and minimizing duplication of simulation activities by NASA and industry.

Key to Tables

ITEM NUMBER - - Reference number for simulations discussed in Report Text (Section 4.2, Results)

FACILITY NUMBER - Indicates the generic facility required for a given simulation activity.

Booster

1 Engineering Crew Station Simulator
2 Crew Station Soft Mockup
3 Crew Station Hard Mockup
4 Medium Fidelity Procedures Trainer (Fixed Base)
5 High Fidelity Mission Trainer (Fixed Base)
6 Centrifuge with Crew Station Simulator
7 Medium Fidelity Procedures Trainer (Motion Base)
8 Variable Stability Aircraft
9 Propellant Handling Facility
10 Systems Integration Laboratory
  o Data Management System Breadboard
  o Hydraulic and Control Systems Test Unit
  o Avionics Systems Test Unit

Orbiter

1 Engineering Crew Station Simulator
2 Engineering Docking Station Simulator
3 Crew Station Soft Mockup
4 Crew Station Hard Mockup
5 Payload Device Mockups
6 Medium Fidelity Procedures Trainer (Fixed Base)
7 High Fidelity Mission Trainer (Fixed Base)
8 Centrifuge with Crew Station Simulator
9 Zero-"g" Aircraft
10 Neutral Buoyancy Facility
11 Docking Procedures Trainer (Motion Base)
12 Medium Fidelity Procedures Trainer (Motion Base)
13 Variable Stability Aircraft

Booster	Orbiter
o Crew Station Mockup	14 Propellant Handling Facility
11 General Purpose Computer	15 Systems Integration Laboratory
	o Data Management System Breadboard
	o Hydraulic and Control Systems Test Unit
	o Avionics Systems Test Unit
	o Crew Station Mockup
	16 General Purpose Computer

TITLE - Represents the applicable SRD title.

SRD NO. - Represents the applicable SRD number.

ACTIVITY - Indicates whether the SRD activity is to be:

- o done by NASA and Contractor in parallel in separate facilities.
- o done by NASA only.
- o done by Contractor only.
- o eliminated as a non-critical activity.

FACILITY - Indicates if the facility to be used is NASA or Contractor

Note: It is recognized that alternative facilities exist in industry and will be utilized when Contractor or NASA-facilities do not meet selection criteria.

BOOSTER				PLAN I			PLAN II		
ITEM	FAC. NO.	TITLE	SRD NO.	ACTIVITY	FACILITY NASA	FACILITY CONTR	ACTIVITY	FACILITY NASA	FACILITY CONTR
1	1	MAN-IN-LOOP DESIGN VERIFICATION	1.1.1.1.1	NASA & Contr	X	X	Contractor Only		X
2	1	MAN-IN-LOOP PROC. DEVEL. & FUNCT.	1.1.1.1.2	NASA & Contr	X	X	Note 1		X
3	1	MANNED BACKUP BOOST CONTROL	1.1.1.1.3	NASA & Contr	X	X	Combine with 1.1.1.1.2		X
4	1	CREW/COMPUTER INTERFACE DESIGN EVALUATION	1.1.2.1.1	NASA & Contr	X	X	Contractor Only		X
5	1	CREW STATION DISPLAY & CONTROL DESIGN VERIF.	1.1.3.1.1	NASA & Contr	X	X	Note 2		X
6	1	VISUAL & AUDITORY WARNING SYSTEM	1.1.3.1.2	NASA & Contr	X	X	Combine with 1.1.1.1.1 & .2		X
7	1	WORKLOAD HUMAN FACTOR ANALYSIS	1.1.6.1.2	NASA & Contr	X	X	Contractor Only Combine with 1.1.1.1.1		X
8	2	CREW STATION SOFT MOCKUP	1.1.5.1.1	Contractor Only		X	Eliminate		
9	3	CREW SYSTEMS 1-"g" MOCKUP	1.1.5.1.2	NASA & Contr	X	X	Contractor Only	Note 3	
10	3	1-"g" FAMILIARIZATION TRAINING	1.2.1.1	NASA Only	X		NASA Only	Note 3	
11	4	CREW MISSION PROCEDURES DEVELOPMENT	1.1.6.1.3	NASA Only	X		NASA Only	X	
12	4	PROCEDURES TRAINING SIMULATION	1.2.1.2	NASA Only	X		NASA Only	X	
13	5	MISSION TRAINING SIMULATION	1.2.3.1	NASA Only	X		NASA Only	X	
14	6	ENVIRONMENTAL SIMULATION OF ASCENT & ENTRY	2.1.1.1.2	NASA Only	X		NASA Only	X	
15	6	HIGH-"g" TRAINING SIMULATION	2.2.1.1	NASA Only	X		Eliminate		
16	7	MOTION BASE FLIGHT TRAINING SIMULATION	2.2.1.2	Note 4	X		NASA Only	X	
17	8	VARIABLE STABILITY A/C FLIGHT SIMULATION	2.1.1.1	NASA Only	X		Eliminate		
18	8	IN-FLIGHT TRAINING SIMULATION	2.2.1.3	NASA Only	X		Eliminate		
19	9	PROPELLANT TANK DRAINAGE	5.1.1.1.5	Contractor Only		X	Contractor Only		X
20	10	HYDRAULIC SUBSYSTEM VERIFICATION	5.4.2.1.2	NASA & Contr	X	X	Contractor Only		X
21	10	DATA MANAGEMENT SYSTEM BREADBOARD	5.2.1.1.1	NASA & Contr	X	X	Contractor Only		X
22	10	FCS/HYDRAULIC SYSTEM INTERFACE VERIFICATION	5.2.2.1.2	NASA & Contr	X	X	Contractor Only		X

BOOSTER				PLAN I			PLAN II		
ITEM	FAC. NO.	TITLE	SRD NO.	ACTIVITY	FACILITY NASA	FACILITY CONTR	ACTIVITY	FACILITY NASA	FACILITY CONTR
23	10	TVC/HYDRAULIC SYSTEM INTERFACE VERIFICATION	5.2.2.1.3	NASA & Contr	X	X	Contractor Only		X
24	10	AUTOPILOT AVIONICS	5.2.3.1.1	NASA & Contr	X	X	Contractor Only		X
25	10	SOFTWARE/HARDWARE VALIDATION	6.1.1.1	NASA & Contr	X	X	Contractor Only		X
26	11	WORKLOAD ANALYSIS	1.1.6.1.1	NASA & Contr	X	X	Eliminate		
27	11	ASCENT/ABORT FLYBACK	3.1.1.1	NASA & Contr	X	X	Contractor Only		X
28	11	THEORETICAL TERMINAL TRANSITION	3.1.1.2	NASA & Contr	X	X	Contractor Only		X
29	11	THEORETICAL APPROACH AND LANDING	3.1.1.3	NASA & Contr	X	X	Contractor Only		X
30	11	FLIGHT TEST SUPPORT	3.1.1.4	NASA & Contr	X	X	Contractor Only		X
31	11	FERRY MISSION SIMULATION	3.1.1.5	NASA & Contr	X	X	Contractor Only		X
32	11	SEPARATION SIMULATION	3.1.3.1	NASA & Contr	X	X	Contractor Only		X
33	11	ASCENT TRAJECTORY	3.1.3.2	NASA & Contr	X	X	Contractor Only		X
34	11	ENGINE OUT TRAJECTORY	3.1.3.3	NASA & Contr	X	X	Contractor Only		X
35	11	VIBRATION SPECTRA	3.2.1.1	Contractor Only		X	Contractor Only		X
36	11	AEROELASTIC STABILITY	3.2.1.2	NASA & Contr	X	X	Contractor Only		X
37	11	ELASTIC VEHICLE/CONTROL	3.2.1.3	NASA & Contr	X	X	Contractor Only		X
38	11	TRANSIENT RESPONSE OF VEHICLE	3.2.1.4	NASA & Contr	X	X	Contractor Only		X
39	11	STRUCTURAL/PROPULSION STABILITY	3.2.3.1	NASA & Contr	X	X	NASA Only	X	
40	11	VEHICLE CONTROL/STRUCTURAL	3.2.3.2	NASA & Contr	X	X	Contractor Only		X
41	11	VEHICLE CONTROL/POGO	3.2.3.3	NASA & Contr	X	X	NASA Only	X	
42	11	TRANSIENT RESPONSE OF VEHICLE	3.2.3.4	NASA & Contr	X	X	Contractor Only		X
43	11	CONTROL SYSTEM SIMULATION	4.1.1.1	NASA & Contr	X	X	Contractor Only		X
44	11	NAVIGATION SYSTEM SIMULATION	4.1.1.2	NASA & Contr	X	X	Contractor Only		X
45	11	GUIDANCE & TARGETING SIMULATION	4.1.1.3	NASA & Contr	X	X	Contractor Only		X
46	11	CLOSED LOOP PERFORMANCE	4.1.1.4	NASA & Contr	X	X	Contractor Only		X
47	11	LANDING SYSTEM ANALYSIS	4.2.1.1	Contractor Only		X	Contractor Only		X

BOOSTER				PLAN I			PLAN II		
ITEM	FAC. NO.	TITLE	SRD NO.	ACTIVITY	FACILITY NASA	FACILITY CONTR	ACTIVITY	FACILITY NASA	FACILITY CONTR
48	11	VEHICLE THERMAL ANALYSIS	4.3.1.1	Contractor Only		X	Contractor Only		X
49	11	THRUST BUILDUP	5.1.1.1.1	NASA & Contr	X	X	Contractor Only		X
50	11	PNEUMATIC CONTROL SYSTEM	5.1.1.1.2	Contractor Only		X	Contractor Only		X
51	11	PROPELLANT DUMPING	5.1.1.1.3	Contractor Only		X	Eliminate		
52	11	FEEDLINE FLOW CHARACTERISTICS	5.1.1.1.4	Contractor Only		X	Contractor Only		X
53	11	ACPS ENGINE FUEL DELIVERY	5.1.2.1.1	Contractor Only		X	Contractor Only		X
54	11	ACPS FUEL CONDITIONING/FEED SYSTEM	5.1.2.1.2	Contractor Only		X	Contractor Only		X
55	11	JET FLAPS CONTROL SIMULATION	5.1.3.1.1	Contractor Only		X	Contractor Only		X
56	11	TVC SYSTEM SIMULATION	5.2.2.1.1	Contractor Only		X	Contractor Only		X
57	11	ECLS SYSTEM SIMULATION	5.3.1.1.1	Contractor Only		X	Contractor Only		X
58	11	DC ELECTRICAL DISTRIBUTION SYSTEM	5.4.1.1.1	Contractor Only		X	Eliminate		
59	11	HYDRAULIC SYSTEM SIMULATION	5.4.2.1.1	Contractor Only		X	Contractor Only		X
60	11	FUNCTIONAL SOFTWARE SIMULATION	7.1.1.1	NASA & Contr	X	X	Contractor Only		X
61	11	FLIGHT SOFTWARE SIMULATION	7.1.1.2	NASA & Contr	X	X	Contractor Only		X
62	11	GROUND CHECKOUT INTERFACE	8.1.1	NASA & Contr	X	X	Contractor Only		X
63	11	SUPPORTABILITY SIMULATION	8.1.2	NASA & Contr	X	X	NASA Only	X	

NOTES:

1. Plan II - Reduction of number of runs (less facility utilization) may be used to reduce cost significantly with a resulting increase in technical risk.
2. Plan II - Eliminate Part I, evaluate hardware in laboratory bench tests.
3. Plan I - 1-"g" mockup at each facility, NASA & contractor
   Plan II - One 1-"g" mockup (at contractor facility during early design stages, transferred to NASA for later training activity)
4. Plan I - Use existing facility to augment in-flight training, new facility not considered feasible.
   Plan II - Develop new facility or modify and use existing facility.

ORBITER				PLAN I			PLAN II		
ITEM	FAC. NO.	TITLE	SRD NO.	ACTIVITY	FACILITY NASA	FACILITY CONTR	ACTIVITY	FACILITY NASA	FACILITY CONTR
1	1	MAN-IN-LOOP GN&C-DESIGN VERIFICATION	1.1.1.2.1	NASA & Contr	X	X	Contractor Only		X
2	1	MAN-IN-LOOP FUNCTIONAL SIMULATION	1.1.1.2.2	NASA & Contr	X	X	Note 1		X
3	1	CREW-COMPUTER INTERFACE DESIGN EVALUATION	1.1.2.2.1	NASA & Contr	X	X	Contractor Only		X
4	1	CREW STATION DISPLAY & CONTROL DESIGN VERIF.	1.1.3.2.1	NASA & Contr	X	X	Note 2		X
5	1	VISUAL & AUDITORY WARNING SYSTEM	1.1.3.2.2	NASA & Contr	X	X	Combine with 1.1.1.1.2		X
6	1	WORKLOAD HUMAN FACTOR ANALYSIS	1.1.6.2.2	NASA & Contr	X	X	Combine with 1.1.1.1.1 & .2		X
7	2	DOCKING PROCEDURES DESIGN ANALYSIS	1.1.1.2.3	Contractor Only		X	Contractor Only Combine with 1.1.1.1.1		X
8	2	SATELLITE PLACEMENT DEVICE DEVELOPMENT	1.1.4.1.1	Contractor Only		X	Eliminate		
9	3	CREW STATION SOFT MOCKUP	1.1.5.2.1	Contractor Only		X	Eliminate		
10	4	CREW SYSTEMS 1-"g" MOCKUP	1.1.5.2.2	NASA & Contr	X	X	Contractor Only	Note	3
11	4	1-"g" FAMILIARIZATION TRAINING	1.2.2.1	NASA Only	X		NASA Only	Note	3
12	5	PAYLOAD DEVICE MOCKUPS	1.2.4.1	NASA Only	X		Eliminate		
13	6	CREW MISSION PROCEDURES DEVELOPMENT	1.1.6.2.3	NASA Only	X		NASA Only	X	
14	6	PROCEDURES TRAINING SIMULATION	1.2.2.2	NASA Only	X		NASA Only	X	
15	7	MISSION TRAINING SIMULATION	1.2.3.1	NASA Only	X		NASA Only	X	
16	7	GROUND CONTROLLER TRAINING	1.2.5.1	NASA Only	X		NASA Only	X	
17	8	ENVIRONMENTAL SIMULATION OF ASCENT & ENTRY	2.1.1.2.1	NASA Only	X		NASA Only	X	
18	8	HIGH -"g" TRAINING SIMULATION	2.2.2.6	NASA Only	X		Eliminate		
19	9	ZERO-"g" FAMILIARIZATION & TRAINING SIM.	2.2.2.1	NASA Only	X		Eliminate		
20	9	Zero-"g" FAMILIARIZATION & TRAINING - CARGO HANDLER	2.2.3.1	NASA Only	X		Eliminate		
21	10	NEUTRAL BUOUANCY MOBILITY TRAINING	2.2.2.2	NASA Only	X		NASA Only	X	
22	10	NEUTRAL BUOUANCY TRAINIG - CARGO HANDLER	2.2.3.2	NASA Only	X		NASA Only	X	

ORBITER				PLAN I			PLAN II		
ITEM	FAC. NO.	TITLE	SRD NO.	ACTIVITY	FACILITY NASA	FACILITY CONTR	ACTIVITY	FACILITY NASA	FACILITY CONTR
23	11	FULL-SCALE DOCKING PROCEDURES TRAINING	2.2.2.5	NASA Only	X		Eliminate		
24	12	MOTION BASE FLIGHT TRAINING SIMULATION	2.2.2.3	Note 4	X		NASA Only	X	
25	13	VARIABLE STABILITY A/C FLIGHT SIMULATION	2.1.1.2.2	NASA Only	X		Eliminate		
26	13	IN-FLIGHT TRAINING SIMULATION	2.2.2.4	NASA Only	X		Eliminate		
27	14	PROPELLANT TANK DRAIN MODEL	5.1.1.2.3	Contractor Only		X	Contractor Only		X
28	14	ACPS/OMS START TANK BREADBOARD	5.1.2.2.4	Contractor Only		X	Eliminate		
29	15	HYDRAULIC SUBSYSTEM VERIFICATION	5.4.2.2.2	NASA & Contr	X	X	Contractor Only		X
30	15	DATA MANAGEMENT SYSTEM BREADBOARD	5.2.1.2.1	NASA & Contr	X	X	Contractor Only		X
31	15	FCS/HYDRAULIC SYSTEM INTERFACE VERIFICATION	5.2.2.2.1	NASA & Contr	X	X	Contractor Only		X
32	15	TVC/HYDRAULIC SYSTEM INTERFACE VERIFICATION	5.2.2.2.2	NASA & Contr	X	X	Contractor Only		X
33	15	AUTOLAND FUNCTIONAL VERIFICATION	5.2.3.2.1	NASA & Contr	X	X	Contractor Only		X
34	15	AUTOPILOT FUNCTIONAL VERIFICATION	5.2.3.2.2	NASA & Contr	X	X	Contractor Only		X
35	15	SOFTWARE/HARDWARE VALIDATION	6.1.2.1	NASA & Contr	X	X	Contractor Only		X
36	16	WORKLOAD ANALYSIS	1.1.6.2.1	NASA & Contr	X	X	Eliminate		
37	16	ASCENT TRAJECTORY	3.1.2.1	NASA & Contr	X	X	Contractor Only		X
38	16	ASCENT/ABORT FLYBACK TRAJECTORY	3.1.2.2	NASA & Contr	X	X	Contractor Only		X
39	16	REENTRY TRAJECTORY	3.1.2.3	NASA & Contr	X	X	Contractor Only		X
40	16	THEORETICAL TERMINAL TRANSITION	3.1.2.4	NASA & Contr	X	X	Contractor Only		X
41	16	THEORETICAL APPROACH & LANDING	3.1.2.5	NASA & Contr	X	X	Contractor Only		X
42	16	THEORETICAL FERRY MISSION	3.1.2.6	NASA & Contr	X	X	Contractor Only		X
43	16	FLIGHT TEST SUPPORT	3.1.2.7	NASA & Contr	X	X	Contractor Only		X
44	16	VIBRATION SPECTRA	3.2.2.1	Contractor Only		X	Contractor Only		X
45	16	AEROELASTIC STABILITY	3.2.2.2	NASA & Contr	X	X	Contractor Only		X
46	16	STRUCTURAL-PROPULSION STABILITY	3.2.2.3	NASA & Contr	X	X	NASA Only	X	
47	16	ELASTIC VEHICLE/CONTROL SURFACE	3.2.2.4	NASA & Contr	X	X	Contractor Only		X
48	16	VEHICLE CONTROL/POGO	3.2.2.5	NASA & Contr	X	X	NASA Only	X	

ORBITER				PLAN I			PLAN II		
ITEM	FAC. NO.	TITLE	SRD NO.	ACTIVITY	FACILITY NASA	FACILITY CONTR	ACTIVITY	FACILITY NASA	FACILITY CONTR
49	16	TRANSIENT RESPONSE OF VEHICLE	3.2.2.6	NASA & Contr	X	X	Contractor Only		X
50	16	CONTROL SYSTEM SIMULATION	4.1.2.1	NASA & Contr	X	X	Contractor Only		X
51	16	NAVIGATION SYSTEM SIMULATION	4.1.2.2	NASA & Contr	X	X	Contractor Only		X
52	16	GUIDANCE & TARGETING SIMULATION	4.1.2.3	NASA & Contr	X	X	Contractor Only		X
53	16	CLOSED LOOP GN&C PERFORMANCE	4.1.2.4	NASA & Contr	X	X	Contractor Only		X
54	16	LANDING SYSTEM ANALYSIS	4.2.2.1	Contractor Only		X	Contractor Only		X
55	16	VEHICLE THERMAL ANALYSIS	4.3.2.1	Contractor Only		X	Contractor Only		X
56	16	FEED SYSTEM/ENGINE INTERFACE	5.1.1.2.1	Contractor Only		X	Contractor Only		X
57	16	PNEUMATIC CONTROL SYSTEM	5.1.1.2.2	Contractor Only		X	Contractor Only		X
58	16	ACPS FUEL CONDITIONING/FEED SYSTEM	5.1.2.2.1	Contractor Only		X	Contractor Only		X
59	16	ACPS ENGINE FUEL DELIVERY	5.1.2.2.2	Contractor Only		X	Contractor Only		X
60	16	OMS ENGINE PROPELLANT DELIVERY	5.1.2.2.3	Contractor Only		X	Contractor Only		X
61	16	ECLS SYSTEM SIMULATION	5.3.1.2.1	Contractor Only		X	Contractor Only		X
62	16	D.C. ELECTRICAL DISTRIBUTION SYSTEM	5.4.1.2.1	Contractor Only		X	Eliminate		
63	16	HYDRAULIC SYSTEM SIMULATION	5.4.2.2.1	Contractor Only		X	Contractor Only		X
64	16	FUNCTIONAL SOFTWARE SIMULATION	7.1.2.1	NASA & Contr	X	X	Contractor Only		X
65	16	FLIGHT SOFTWARE VERIFICATION	7.1.2.2	NASA & Contr	X	X	Contractor Only		X
66	16	GROUND CHECKOUT INTERFACE	8.2.1	NASA & Contr	X	X	Contractor Only		X
67	16	SUPPORTABILITY ANALYSIS	8.2.2	NASA & Contr	X	X	NASA Only	X	
68	16	MISSION OPERATIONS ANALYSIS	8.3.1	NASA & Contr	X	X	NASA Only	X	
69	16	FUEL LOADING PROCESS MANAGEMENT	8.3.2	NASA & Contr	X	X	NASA Only	X	

ORBITER				PLAN I			PLAN II		
ITEM	FAC. NO.	TITLE	SRD NO.	ACTIVITY	FACILITY		ACTIVITY	FACILITY	
					NASA	CONTR		NASA	CONTR

1. Plan I - Reduction of number of runs (less facility utilization) may be used to reduce cost with a resulting increase in technical risk.

2. Plan II - Eliminate Part I, evaluate hardware in laboratory bench tests.

3. Plan I - 1-"g" mockup at each facility, NASA & Contractor.
   Plan II - One 1-"g" mockup (at contractor facility during early design stages, transferred to NASA for later training activity)

4. Plan I - Use existing facility to augment in-flight training; new facility not considered.
   Plan II - Develop new facility or modify and use existing facility.

APPENDIX C
MATH MODELS
OF
REFERENCE ENVIRONMENT

The booster or orbiter all-digital reference environment programs are six-degree-of-freedom simulations of each vehicle's rigid body dynamic motions in the real world environment. Consequently, the best available math models and computational techniques shall be used in order to achieve the most realistic results.

The math models required for this simulation are:

- o Gravitational Potential
  - o Ascent - inverse square law
  - o On Orbit/Reentry - aspherical earth through the fourth harmonic
  - o Subsonic Airplane - constant acceleration
- o Atmosphere Model
  - o Subsonic Airplane - standard day
  - o Wind, wind shear and gusts
  - o High altitude - Jacchia model
- o Vehicle Model
  - o Mass as function of consumables with time
  - o C.G. as a function of time
  - o Moments of inertia as function of time
- o Aerodynamics (including control surfaces)
  - o Mated vehicle
  - o Booster only - return, transition, subsonic airplane
  - o Orbiter only - on orbit, reentry, transition, subsonic airplane
- o Propulsion System
  - o Main booster & orbiter
  - o Attitude control
  - o Deorbit
  - o Air breathing
  - o OMS

- o Control System (Perfect)
  - o Attitude hold
  - o Attitude rate
  - o Attitude/attitude rate
- o Disturbances
  - o Overboard dumping & venting
  - o Cargo handling

The rigid-body dynamic response is determined by the equations of motion. The accelerations acting on the vehicle's center of gravity, primarily thrust, gravity, and aerodynamic, are accurately integrated to obtain the translational motion. The rotational motion accounts for torques about the center of gravity primarily caused by thrust, aerodynamics, and disturbances.

Coordinate systems used will vary depending upon the particular application. The following coordinate systems and the transformations relating them will be required:

- o Geocentric inertial
- o Earth centered rotating
- o Vehicle body fixed
- o Vehicle body inertial
- o Geodetic inertial
- o Wind axes
- o Target centered relative
- o Down range - crossrange

Utilization of this simulation program requires the capability for stand alone operation and as an environmental subprogram for other simulations. Accordingly, nearly all parameters should be included in a "common" statement and all input/output routines and statements selectable via input. Stand alone operation will be used for mission and operations planning, e.g. rendezvous phasing, ascent targeting, event scheduling and initial condition generation. Operation as an environmental subprogram will be for studies and analyses in the areas of guidance, navigation and control.

This simulation program may be executed in the described stand alone mode on any general purpose digital computer with standard peripherals. However, other uses for the program, e.g., as the environment for a man-in-the-loop simulation,

will require the host computer to interface with a simulated crew station. Consequently, the facility for execution of this program varies according to its use.

APPENDIX D
ENGINEERING CREW STATION SIMULATOR

The engineering crew station simulator will be a fixed-base simulator comprised of a crew station mockup, the visual simulations, the subsystem controls and displays, flight crew/computer interface, linkage, and a general purpose digital computer.

A diagram illustrating the key elements of the engineering crew station simulator required for the Booster and Orbiter is shown in Figure 1. The simulator provides a functional simulation in that math models are used to simulate vehicle systems operation rather than this function being performed by actual equipment. The subsystem displays and controls are an exception, and function to provide a realistic interface with man in the real world and the simulated functions of the vehicle.

Displays and controls located in the crew station are actual equipment, prototypes, or realistic simulations. Active and inactive displays and controls are provided in the crew station. A list of these equipments is presented in Figure 2. Generally, active displays and controls apply to equipment required to perform detailed man-in-the-loop functional GN&C simulations. Inactive displays and controls generally represent dedicated subsystems management equipment. These displays and controls are not normally required except for specific short term needs.

The crew/computer interface system is required by the crew to maintain control of the flight computer via the data bus system. This interface is composed of keyboards for inserting data into the flight computer and multiple CRT displays for readout. The Booster and Orbiter vehicles have a compliment of three Cathode Ray Tubes (CRT's) with keyboards which the flight crews will use to monitor vehicle systems status, alter systems operation, and control the various computer modes. The CRT crew/computer interface shall be a commercial graphic display system configured to simulate vehicle hardware. The graphic display system shall be driven by an auxiliary computer linked to the general purpose digital simulation computer.

In addition to displays and controls, the crew station mockup shall be geometrically representative of the actual crew station (either Booster or

(Orbiter). Interior accommodations shall be similar in terms of general envelopes without extreme detail. Lighting shall be representative of the actual crew station.

Visual simulations representing out-the-window displays are mounted onto the simulated crew station windows. The visual simulations involve several closed circuit TV systems with servoed cameras and models required to provide all-attitude geometry. Virtual image optics are used to enhance the fidelity of the video images seen by the observer in the cockpit. Basic displays presented are, rendezvous/docking (with an earth-star field background), for Orbiter simulations, and transition, reentry and landing scenes for Booster and Orbiter simulations. The transition and landing displays are generated by horizon displays and terrain models.

Another element of the simulator complex shown in Figure 1 is the linkage between crew station and general purpose computer. Primarily, the linkage consists of A/D and D/A signal conversions and discrete logic level inputs and outputs. The computer simulation of vehicle dynamics, environment, and systems status receives input signals from the crew station (e.g. hand controller, rudder pedals, keyboard inputs, etc.) dictating changes in vehicle status. The computer then recomputes and updates in real time through the linkage to crew station displays, out-the-window views, and aural cues. Outputs from the computer are also interfaced with an auxiliary computer to update the crew station cathode ray tube (CRT) displays.

The last element of Figure 1, the general purpose computer, provides the programs which functionally simulate the basic vehicle dynamics and all its subsystems. The time reference in the general purpose computer is used to synchronize the computer outputs to crew station with real-time mission events. The simulator executive program schedules the computations and input/output operations required for the simulation to perform correctly. The operating system, interfaces the simulation programs with the computer. The vehicle simulations are the equations of motion, the geometry for mechanizing the visual simulations and the equations for parameters to be measured by the sensors (e.g., altitude, attitude, airspeed, and range). A list of the vehicle simulation math models is given in Appendix A. The subsystem controls and displays simulations are functional (logic and math) models of each vehicle subsystem. The flight software also shall be simulated functionally on the general purpose computer as it becomes available.

The flight software simulation, which is the largest part of the simulator program, is normally only partially done depending upon the objectives of the simulator involved and of the test objectives. Because of this, and the possibility of other simulators required by the NASA for the Space Shuttle program, close coordination of the flight software simulations with the NASA and other prime vehicle contractors will be necessary.

A functional flow diagram of the Shuttle simulation program is provided in Figure 3. This diagram depicts the functional relationship between simulation math models, computer-crew station interface, hardware displays and controls, and pilot.

The computer complex required for the crew systems simulator is a general purpose digital computer with appropriate peripheral equipment and auxiliary computer to drive the graphic CRT displays. The computer requires a central processor with 60 bit word, 98k memory, 10 peripheral processors with 12 bit word and 4k each of memory and major and minor cycles of 1 microsecond and 100 nanoseconds, respectively. Other features shall include:

12	12-bit I/O channels (2 megacycle character transfer rate)
2	Line printers
1	Card reader
1	Dual CRT console
3	Magnetic tape units
6	Remote CRT consoles
1	Disk file with 75,000,000 character capacity
2	Remote terminal multiplexers

Control for initializing and activating the computer is provided by an input terminal located in the control room. A multi-channel recorder in the control room, provides a time history of various parameters selected at the beginning of a run as part of the computer initialization.

A control unit at the simulator allows the test conductor to:

- o Hold (freeze) the simulation
- o Read and/or change parameters during a run
- o Print the hold conditions
- o Selectively inhibit translations and/or rotations for special investigations
- o Reset to pre-programmed initial conditions
- o Terminate the simulation

Some of the additional equipment required to operate the crew system simulator are: electronics, a patch panel, a sound simulator, and power supplies.

Electronics - The simulator electronics shall be housed in cabinets in a room adjacent to the simulator crew station and shall be composed of the computer interface unit, a patch panel for signal and power distribution, sound simulation equipment, power supplies, and other electronics required for driving the flight controls feel systems, and crew station panel instruments.

Patch Panel - All control signals from the computer are routed through the patch panel to the appropriate electronics and/or various crew station displays and controls. This provides flexibility in making simulator configuration changes.

Sound Simulator - The sound simulator provides aural cues of aerodynamic, engine, runway and thruster noises needed for simulation. Stereo sound effects are provided by speakers located on the aft bulkhead, over the side consoles, and in the center window.

Power Supplies - Power supplies are provided for display lighting, alphanumeric display, switching logic inputs, and cockpit instruments.

KEY ELEMENTS OF THE ENGINEERING CREW STATION SIMULATOR

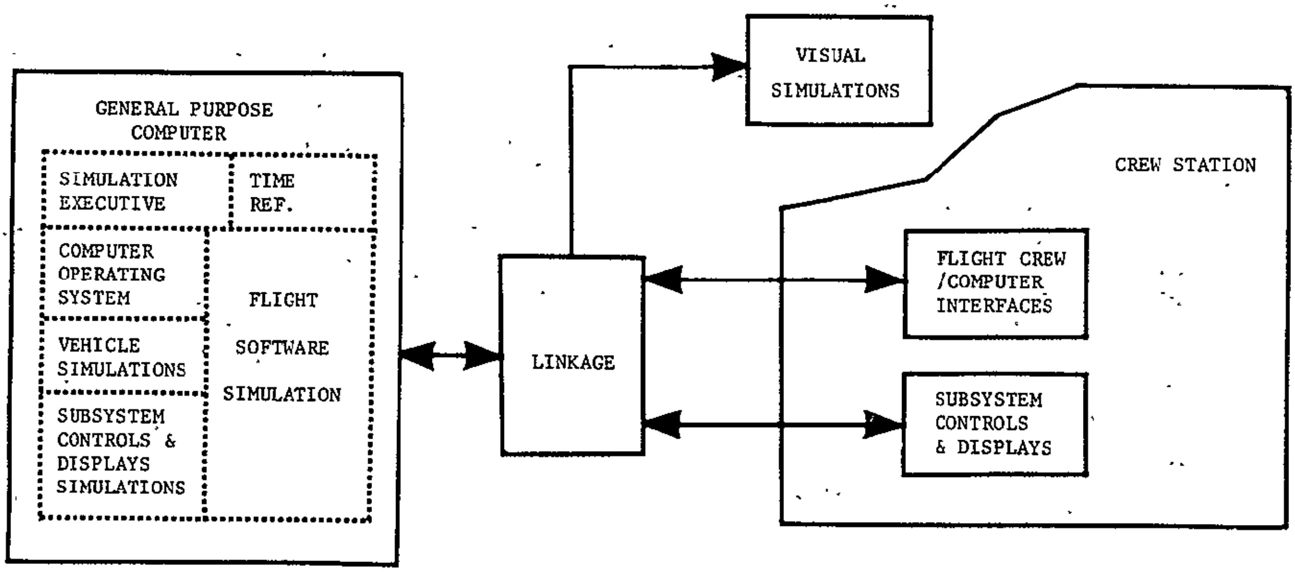
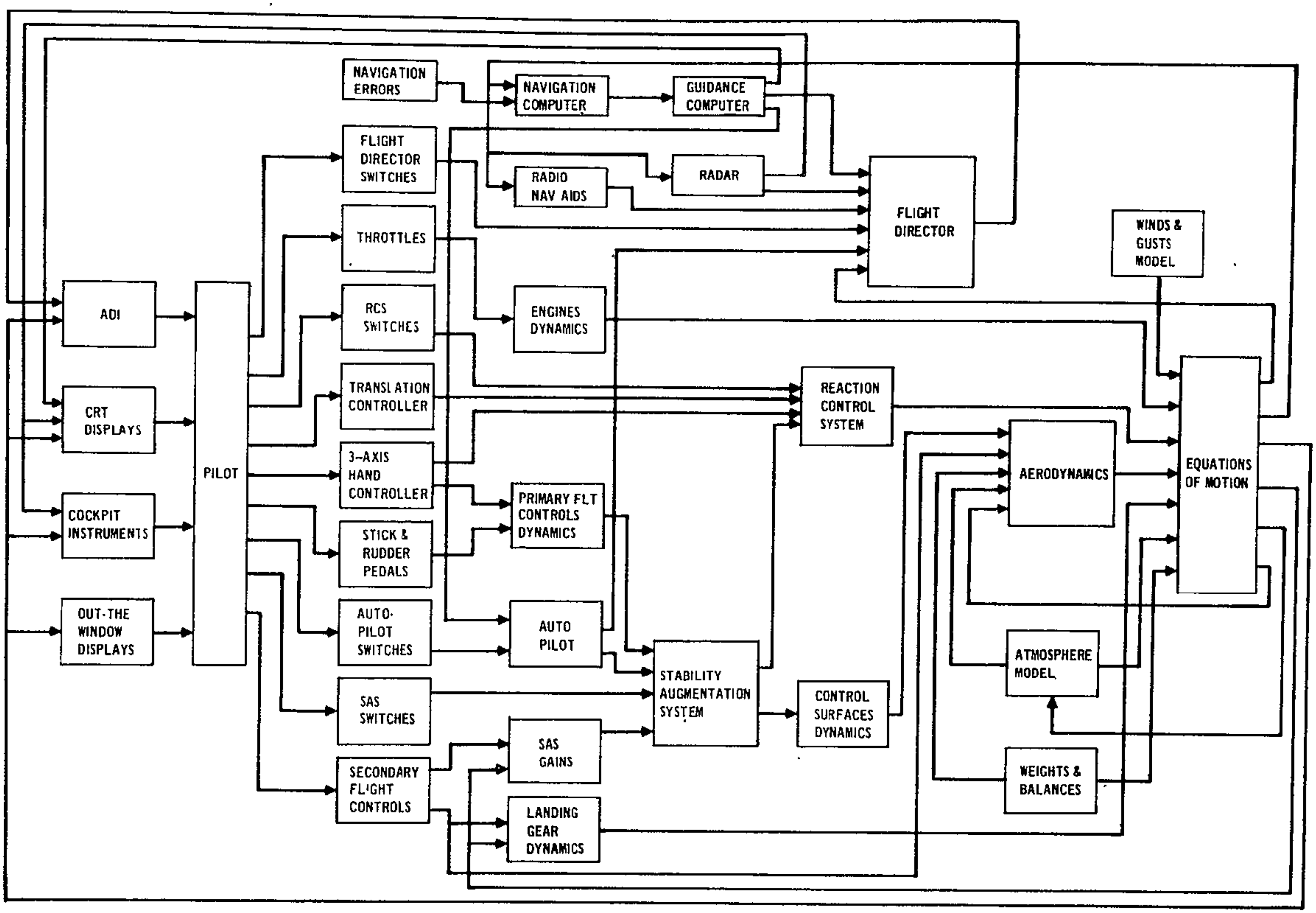


FIGURE 1

ENGINEERING CREW STATION SIMULATOR DISPLAYS AND CONTROLS

ACTIVE	INACTIVE
CONTROL STICK	ORBIT PROPULSION SYSTEM
RUDDER PEDALS	MAIN ENGINES
THROTTLES	FUEL TRANSFER & VENT TANK
ATTITUDE HAND CONTROLLERS	PAY LOAD CONTROLS
TRANSLATION CONTROLLERS	VOICE COMMUNICATIONS
NOSE WHEEL STEERING	VOICE COMMUNICATIONS SELECT
LANDING GEAR	VOICE COMMUNICATIONS FREQUENCY SELECT
FLAPS	VOICE COMMUNICATIONS FREQUENCY DISPLAY
ABORT	AUXILIARY POINTER
ADI	COMPUTER CONTROL PANEL
ALTIMETER	ECLS
RADAR ALTIMETER	HYDRAULICS DISPLAYS
MACH/AIRSPEED	ELECTRICAL DISPLAYS
ANGLE OF ATTACK	FIRE EXT. CONTROLS
ACCELEROMETER	BUILT-IN-TEST
RATE OF CLIMB	FUEL CELL & POWER DIST.
HSI	APU & HYD. SYS. CONTROLS
CAUTION AND WARNING LIGHTS	CIRCUIT PROTECTION
VOR/DME & ILS SELECT	STANDBY ATTITUDE INDICATOR
KEYBOARDS	AUTO CHECKLIST
TRANSLATION CONTROL PANEL	
CRT (GRAPHICS) DISPLAYS	
ELAPSED TIME	
GMT	
EVENT TIMERS	
DME DISPLAY	
VOR/DME & ILS FREQUENCY DISPLAY	
VOR/DME & ILS FREQUENCY SELECT	
NAVIGATION SENSORS	
NAVIGATION POSITION	
RANGE RATE	
AUTO CHECKLIST	
LIGHTING, VENT, AND SEAT CONTROLS	

FIGURE 2



SPACE SHUTTLE SIMULATION PROGRAM

FIGURE 3

APPENDIX E

SYSTEMS INTEGRATION LABORATORY

The Systems Integration Laboratory (SIL) is a unified laboratory complex containing all the electrical, hydraulic, control systems and electronic hardware and software necessary for the integration and development of the flight vehicle and ground support systems. All the hardware should be functionally equivalent to the intended production article and consist of qualified, prototype, or simulated equipment, in that order of precedence.

The SIL should be composed of three basic groups of equipment; an "Iron Bird" Hydraulic and Control Test Unit (HCTU) for hydraulic and control systems development and integration; an Avionics System Test Unit (ASTU) for avionics development and integration; and a crew systems simulator for development and integration tasks requiring man-in-the-loop simulations. In addition, the SIL facility shall contain all GSE equipment required to support vehicle hardware development, GSE development, and GSE integration with vehicle hardware systems.

The Systems Integration Laboratory facility shall be designed for evolutionary growth as the vehicle development programs progress. Starting with a basic hardware breadboard simulation of the data management system the facility shall grow by parallel development of the Hydraulics and Controls Systems Test Unit (HCTU) and the Avionics Systems Test Unit (ASTU) which will eventually replace the early data management system breadboard. The HCTU and ASTU will be used for systems development, and will be capable of independent operation prior to integration into the full-scale Systems Integration Laboratory.

The Hydraulic and Control Test Unit should be composed of a static "Iron Bird" structure with a complete ship set hydraulic system and electrical cables, simulated aerodynamic control surfaces to full thrust gimbals and simulated loads. A pictorial representation of the Booster HCTU is shown in Figure 1. Figure 2 presents a table of actual, simulated, and GSE equipment that makes up the major portion of the typical Booster and Orbiter HCTU facilities. Avionics data management and control functions required for HCTU operation are provided by a commercial computer and the data management system breadboard. APU power to the hydraulic pumps and the electrical power supplies is simulated. The minimum crew station mockup has the necessary dedicated display and control hardware to serve as a crew station during early development phases.

The ASTU shall consist of a complete ship set of production-type avionics hardware. Installation of the equipment, data-bus cable lengths and interfaces with the actual vehicle electrical power system will be duplicated within practical limits. Representative vehicle structure should be minimized. Nonavionic system interfaces, with the exception of the electrical distribution system, should be represented with software (simulation on commercial computer), simple hardware simulators, or GSE equipment.

A pictorial representation of the Booster ASTU is shown in Figure 3. Figure 4 presents a table of actual, simulated, and GSE equipment that comprises a major portion of the typical Booster and Orbiter ASTU facilities.

Upon completion of parallel development tests and simulations, the ASTU and HCTU are integrated for more detailed interface verification tests and simulations. At this point the simulated data bus used for operating the HCTU is no longer used and the ASTU now performs this function. The engineering crew station simulator (Appendix D) is added to perform man-in-loop functional simulations of vehicle performance for all mission phases using a large percentage of actual vehicle hardware. Final simulation testing to be conducted on the full-scale systems integration laboratory is software/hardware validation simulations prior to horizontal flight test and vertical flight test. These full-up simulations validate compatibility of onboard software and vehicle hardware for all mission phases. Systems which are specifically excluded from the SIL are the main propulsion, airbreathing engines, and attitude control propulsion systems. These systems shall be simulated on the data bus using GSE and simulation software (commercial computer). The simulation computer shall also provide vehicle equations of motion and reference environment for the engineering crew station simulator as described in Appendix C.

HYDRAULICS & CONTROLS TEST UNIT (HCTU) – BOOSTER

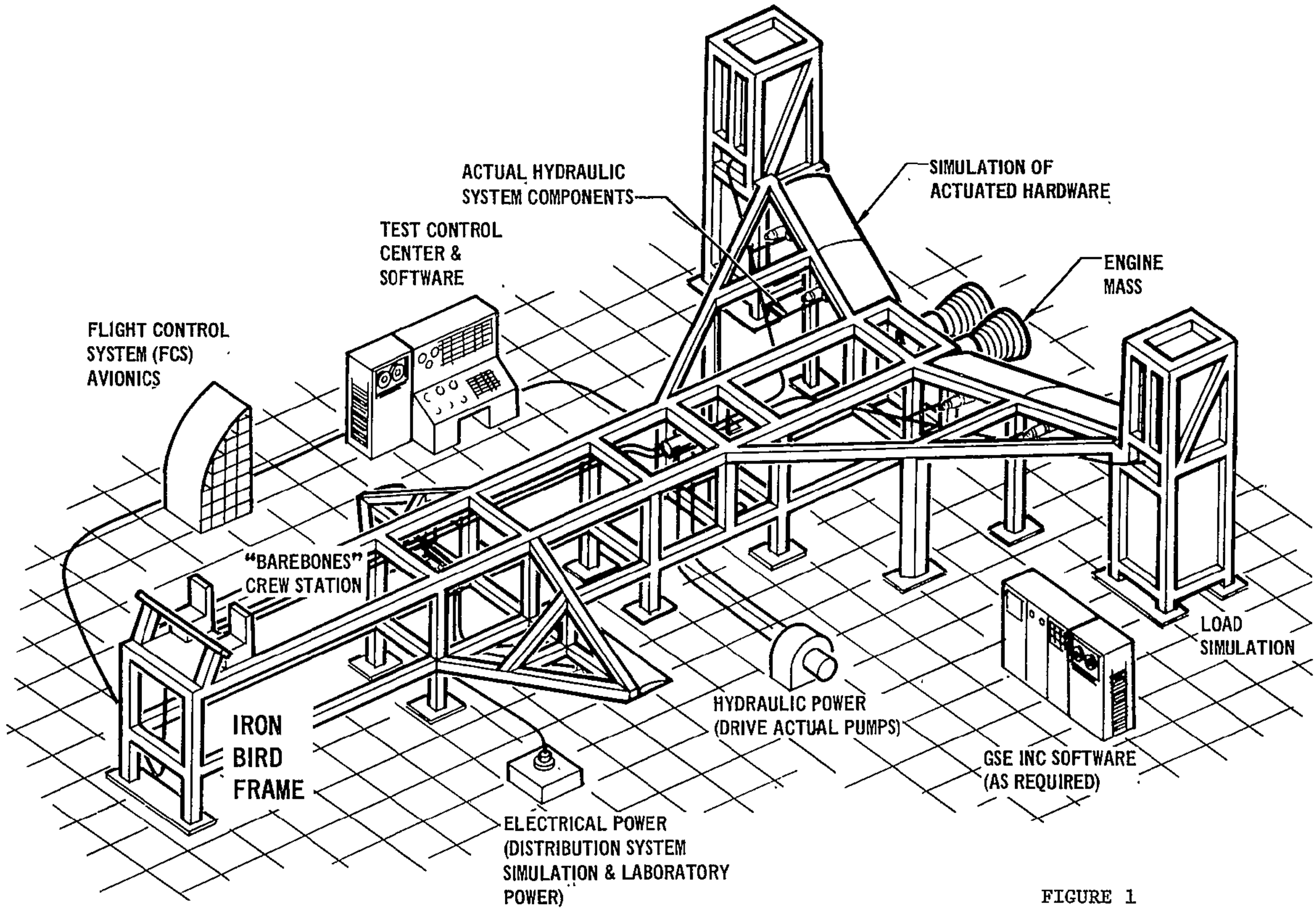


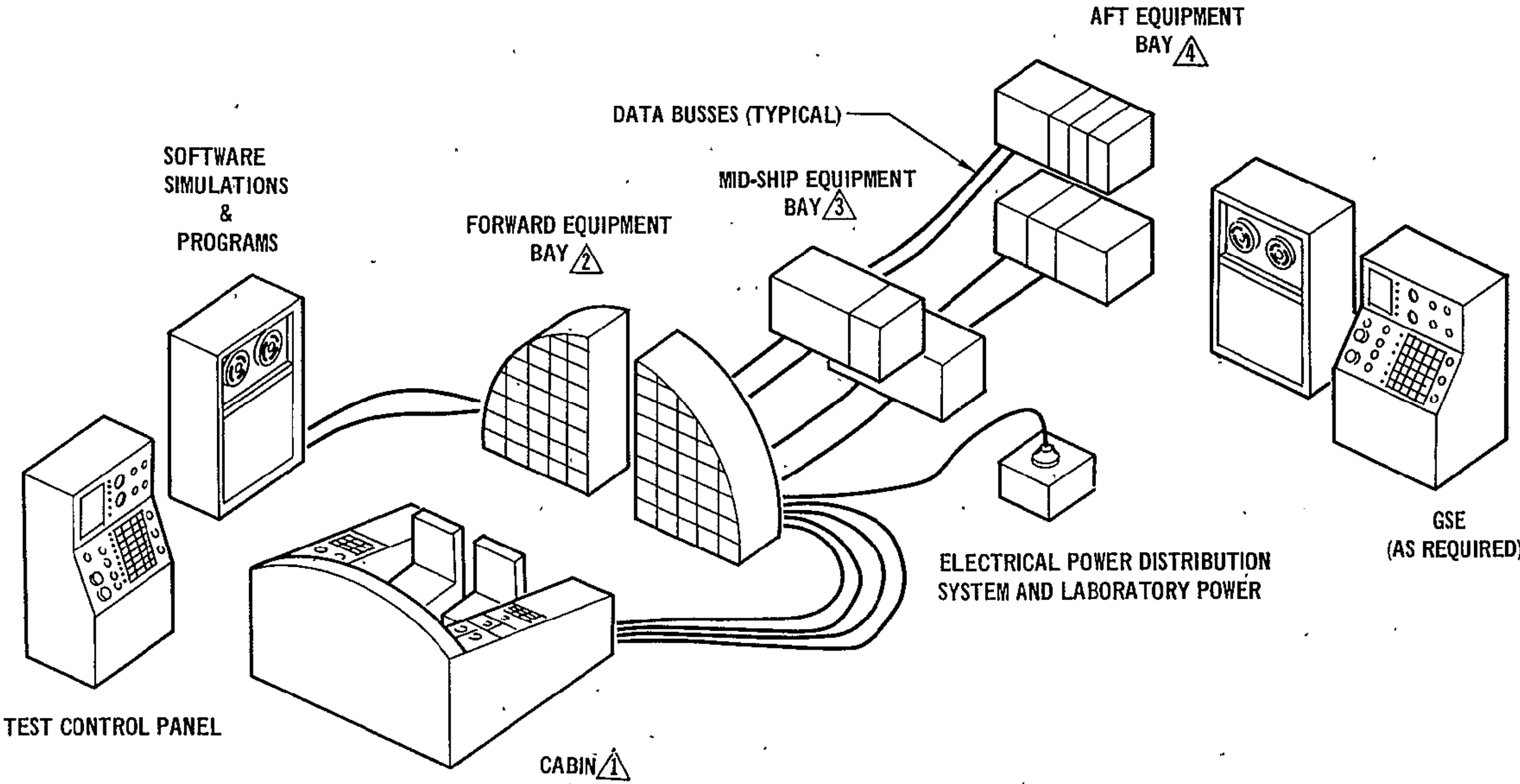
FIGURE 1

HYDRAULICS AND CONTROLS TEST UNIT (HCTU) DESCRIPTION

EQUIPMENT	SIMULATORS	GSE
1. COMPLETE SHIP SET OF HYDRAULICS EQUIPMENT o LANDING GEAR & DOOR ACTUATION o NOSE GEAR STEERING o SPEED BRAKE ACTUATION o ANTI-SKID BRAKES o FLIGHT CONTROLS o THRUST VECTOR CONTROL o ABES DEPLOYMENT 2. REQUIRED FCS & HYDRAULIC CREW STATION CONTROLS AND DISPLAYS 3. SET OF HYDRAULIC/ELECTRIC INTERFACE EQUIPMENT 4. DEVELOPMENT FLIGHT TEST INSTRUMENTATION	1. HARDWARE o GEAR STRUTS & WHEELS o ONE SHIP SET OF CONTROL SURFACES (INCLUDING SPEED BRAKES) o ELECTRICAL POWER o MINIMUM CREW STATION MOCKUP o LOAD DEVICES FOR CONTROL SURFACES o MASTER TEST CONDUCTOR CONSOLE o APU (DRIVE ACTUAL PUMPS) o DATA BUS o MAIN ENGINES (MASS ONLY) o FLUID COOLING 2. SOFTWARE o DATA MANAGEMENT o LOAD PROGRAMS o FCS PROGRAMS	1. HYDRAULIC SYSTEM CHECKOUT ADAPTER UNIT 2. HYDRAULIC GROUND UNIT 3. HYDRAULIC SERVICE AND FLUSH UNIT

FIGURE 2

AVIONICS SYSTEM TEST UNIT (ASTU)
Booster



1. CONTROLS, DISPLAYS, SYSTEM CONTROL UNIT, INTERCOMM & DIUS
2. COMPUTER, MASS MEMORY, IMU, THRUSTER ELECTRONICS, DIUS, NAVAID RADAR ALTIMETER, UHF TRANSCEIVER, & ATC TRANSPONDER.
3. RATE GYROS, FLIGHT CONTROL ELECTRONICS & DIUS
4. FLIGHT CONTROL ELECTRONICS, THRUSTER ELECTRONICS, & DIUS (NOTE ELECTRICAL POWER DISTRIBUTION UNITS AT EACH LOCATION)

FIGURE 3

AVIONICS SYSTEMS TEST UNIT (ASTU) DESCRIPTION

EQUIPMENT	SIMULATORS	GSE
1. COMPLETE SHIP SET OF AVIONICS EQUIPMENT (REDUNDANT) o GUIDANCE AND NAVIGATION o DATA MANAGEMENT o FLIGHT CONTROL ELECTRONICS o COMMUNICATION AND NAVAIDS o DISPLAYS & CONTROLS o SOFTWARE (EXECUTIVE ETC.) 2. COMPLETE SHIP SET OF ELECTRICAL DISTRIBUTION EQUIPMENT o BUSSES o CIRCUIT BREAKERS o FUSES o POWER DISTRIBUTION UNITS (PDU) 3. DEVELOPMENT FLIGHT TEST INSTRUMENTATION	1. HARDWARE o EQUIPMENT BAYS o ELECTRICAL POWER o ELECTRICAL LOADS-LIGHTS, ETC. o ANTENNA LOADS o INSTRUMENT PANEL MOCKUP o MASTER TEST CONTROL PANEL 2. SOFTWARE o HYDRAULIC SYSTEM o ECLS SYSTEM o PROPULSION SYSTEM (MAIN, ACPS & ABE) o FUEL SYSTEM o IMU REFERENCE PROGRAM o STAR TRACKER & HORIZON SENSOR o COMMUNICATION AND NAVAID INPUT PROGRAMS	1. ORBITER TO BOOSTER ELECTRICAL SIMULATION 2. BOOSTER INTERFACE SIMULATOR 3. DC POWER SUPPLY 4. AC POWER SUPPLY 5. BUS QUALITY TEST SET 6. GUIDANCE & NAVIGATION GSE 7. DISPLAY & CONTROL GSE 8. FCS GSE 9. DATA MANAGEMENT GSE 10. COMMUNICATION & NAVAID TEST SETS 11. MONITOR & DISPLAY CONSOLE 12. SOFTWARE 13. SERVICING DIU 14. SYSTEM CONTROL UNIT 15. MISC. CABLING, ETC. 16. NON-AVIONIC SUBSYSTEM GSE THAT INTERFACES WITH AVIONICS

FIGURE 4

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